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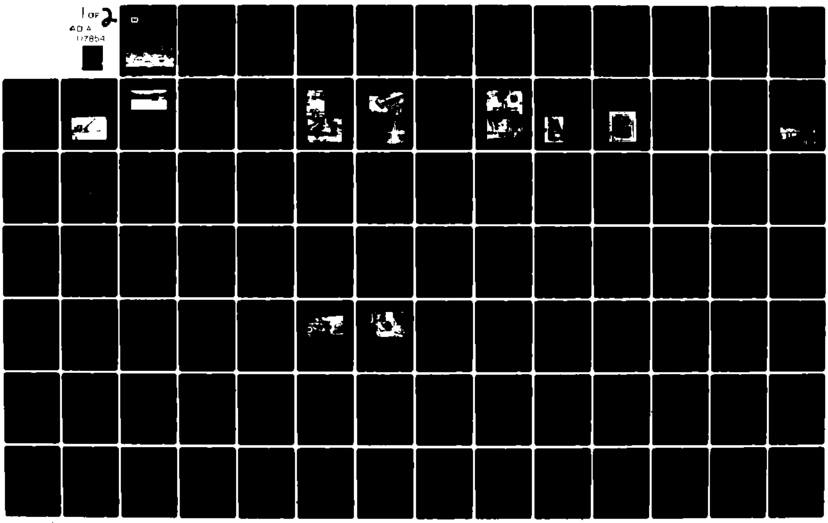

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TECHNICAL REPORT HL-82-8

PUMPING PERFORMANCE AND TURBIDITY GENERATION OF MODEL 600/100 PNEUMA PUMP

MAIN TEXT AND APPENDIXES A AND B

by

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Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Report describes full-scale tests of patented, air-operated solids handling device called the PNEUMA pump. Pump was tested in a river channel, lock entrance, tidal inlet, and dock area in both sand and fine-grained sediment. Report describes test procedures, equipment, instrumentation, and data reduction. Results are evaluated in terms of pumping performance and turbidity generated in fine-grained sediment. Pump could dredge in situ densities in fine-grained sediment but could not in sand. Difficulty was experienced in

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20. ABSTRACT (Continued).

sustaining high discharge densities. Power efficiencies of pump were low. No significant turbidity was measured when dredging fine-grained sediment. Appendix A gives graphical presentations of performance parameters for each test run. Appendix B presents tables of measured turbidity values. Appendix C (bound separately) contains tables of measured data and calculated parameters interpolated at 9-sec intervals for each test run.

PREFACE

Investigations described in this report were accomplished from August to October 1978 under the sponsorship of the Office, Chief of Engineers, U. S. Army, through the U. S. Army Engineer District, Wilmington, N. C. Work was performed under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory, R. A. Sager, Chief of the Estuaries Division, and E. C. McNair, Jr., Chief of the Research Projects Group. Mr. T. W. Richardson was project engineer. Mr. J. E. Hite, Jr., of the Hydraulic Analysis Division supervised field data collection, and Mr. R. A. Shafer of the Environmental Laboratory performed the turbidity generation tests. Mr. J. D. Ethridge, Jr., provided computer programming expertise for data reduction and presentation. Mr. D. M Howard was the Wilmington District project engineer.

Commanders and Directors of WES during the conduct of this work and the preparation and publication of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per minute	0.02831685	cubic metres per minute
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet of water	304.8	kilograms per square metre
feet per second	0.3048	metres per second
gallons per minute	0.06308	litres per second
inches	25.4	millimetres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (force) per square inch	6894.757	pascals
tons (2,000 lb, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

PUMPING PERFORMANCE AND TURBIDITY GENERATION OF MODEL 600/100 PNEUMA PUMP

PART I: INTRODUCTION

Background

1. In September 1977, the Hydraulics Laboratory (HL) of the U. S. Army Engineer Waterways Experiment Station (WES) was requested by the Office, Chief of Engineers, to participate with the U. S. Army Engineer District, Wilmington (SAW), in field-testing a solids handling device known as the PNEUMA pump. The PNEUMA pump at that time was patented and manufactured by S.I.R.S.I., S.p.A., of Florence, Italy. The U. S. franchisee was PNEUMA North America of Libertyville, Illinois.* The purpose of this testing was threefold:

- a. Evaluate usefulness of the PNEUMA pump in a variety of District maintenance dredging situations.
- b. Evaluate pumping performance in different types of material. Special emphasis was placed on evaluating manufacturer's claim of high solids content pumping ability.
- c. Evaluate turbidity generation by pump in loosely consolidated, fine-grained sediments. Manufacturer claims that pump produces little or no increase in water column turbidity when pumping this type of material.

2. Item a was the responsibility of SAW; items b and c were accomplished by WES. SAW provided equipment and personnel for pump deployment and arranged for use of test sites. WES provided instrumentation and personnel to perform items b and c. Design and execution of tests were a joint SAW-WES effort.

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* Current name and address of company is: AMTEC Development Co., 1550 Berkeley Rd., Highland Park, Ill. 60035.

General Test Program

3. The initial progam outlined by WES and SAW was to test four types of sites--a lock approach, a tidal inlet, a dock or bulkhead location, and a hydroelectric dam. Material at the first two sites was anticipated to be sand and at the latter two, fine-grained sediments. Water depths at the first three sites were moderate (up to 35 ft*), while the fourth site was to provide a deepwater test (up to 100 ft).

4. Physical and environmental restrictions at the first and third sites prevented land disposal of dredged material via a pipeline. At these locations, it was necessary to pump into a barge and dump material at approved locations. At the tidal inlet site, it was possible to discharge through a pipeline and vary pipeline length as required.

5. Disposal at the hydroelectric dam site proved to be a problem, due mainly to environmental objections. Testing at this site subsequently was eliminated from the program, meaning no deepwater pumping data were collected.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

PART II: TEST AND EQUIPMENT DETAILS

PNEUMA Pump

6. A brief explanation of the PNEUMA pump is needed to preface the tests and results. The PNEUMA pump is a compressed-air-driven, displacement-type pump with several major components. The pump body (Figure 1), the largest of these components in dimensions and weight, incorporates three large cylindrical pressure vessels, each having a

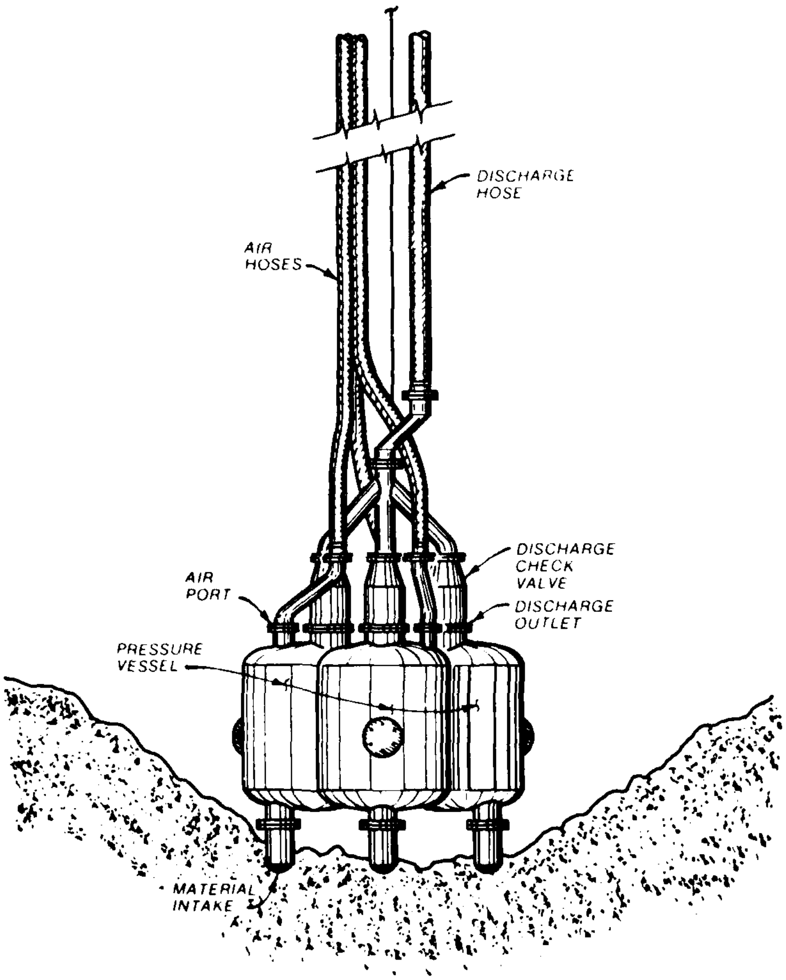


Figure 1. PNEUMA pump body

material intake on the bottom and an air port and discharge outlet on top. Each intake and discharge outlet is fitted with a check valve, allowing flow in one direction only. Pipes leading from the three discharge outlets join in a single discharge directly above the pressure vessels. Different types of attachments may be fitted on the intakes for removal of varying types of bottom material.

7. The operation principle of the pump body is illustrated in Figure 2. When dredging, the body is placed on the bottom with material intakes buried. Venting an air port to atmospheric pressure causes flow into a material intake driven by ambient water pressure. This continues until the pressure vessel is nearly full, at which time compressed air enters the pressure vessel through the air port. The compressed air forces material out of the pressure vessel through the discharge outlet and on to its final destination. The pressure vessels are operated so that filling/emptying cycles are out of phase but overlap enough to minimize discharge surging.

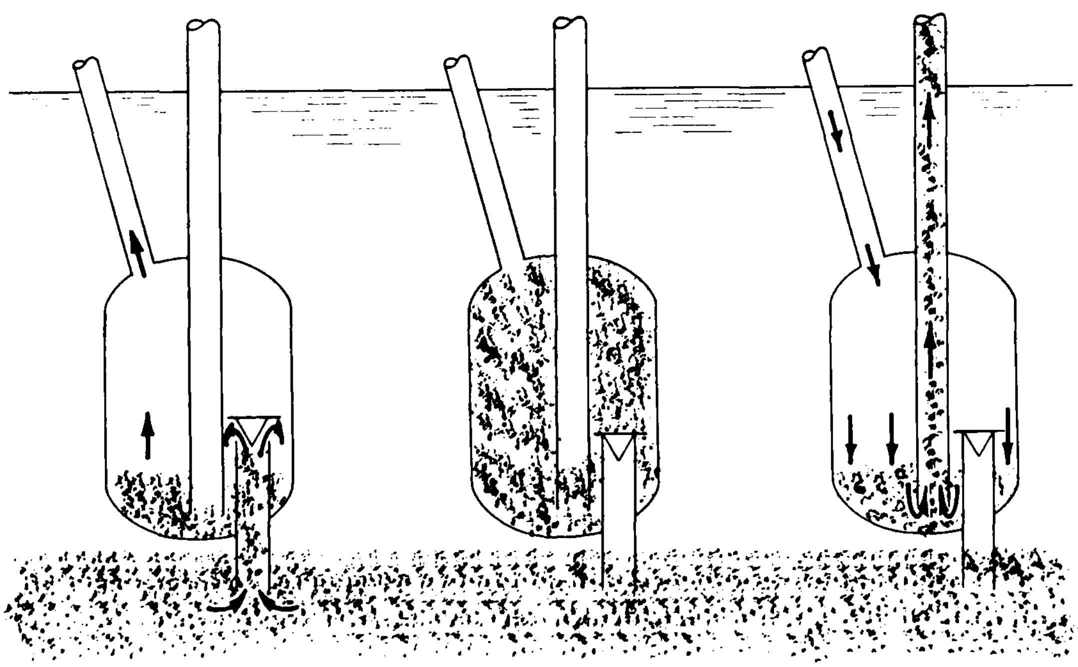


Figure 2. PNEUMA pump principle of operation

8. Timing and rate of pressure vessel cycles are controlled by an electrically driven air distributor (Figure 3). The heart of this device is a multiported spool valve rotated at a variable rate. Compressed air entering the valve is directed to a pressure vessel air port, while simultaneously another port is vented to the atmosphere. Variation of the valve rotational speed controls the pressure vessel cycle rate.

9. The air distributor is connected to the pump body by three flexible hoses, each leading to a pressure vessel air port. A single flexible hose runs from the pump body discharge manifold back to the surface, where it connects to the surface discharge pipeline. The pump body and hoses are usually suspended by a harness from a crane or lifting frame, although other types of support are possible. Figure 4 shows a simple arrangement of all major pump components.

10. At the time of testing, the manufacturer produced six standard models of the PNEUMA pump. The pump tested was designated as Model 600/100. Figure 5 describes the pump body dimensions of standard models.

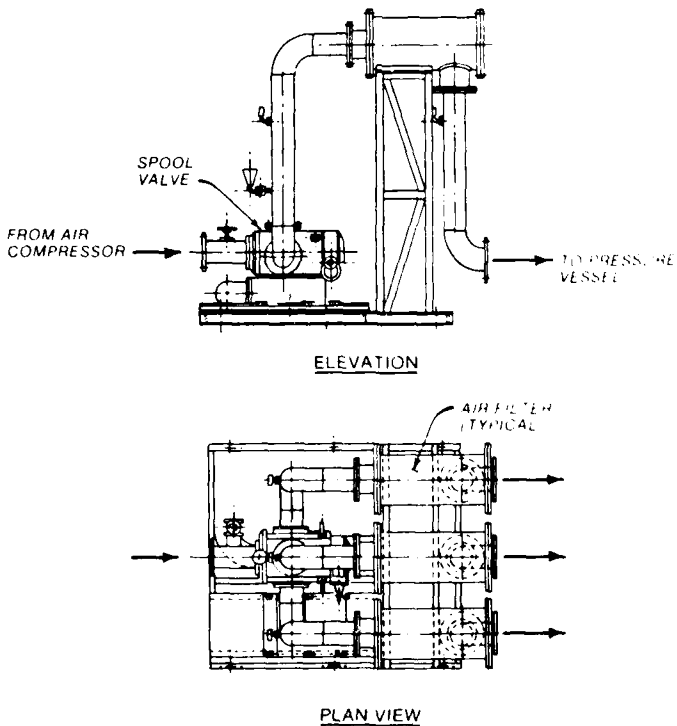


Figure 3. PNEUMA pump air distributor

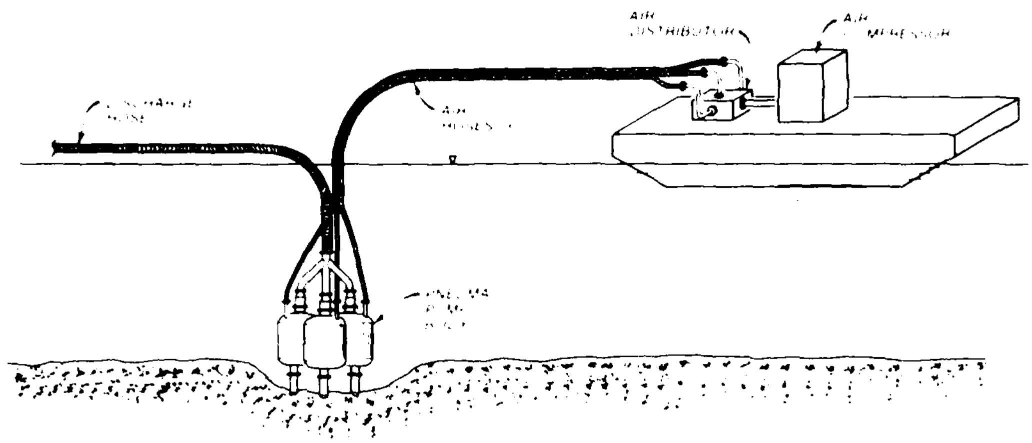
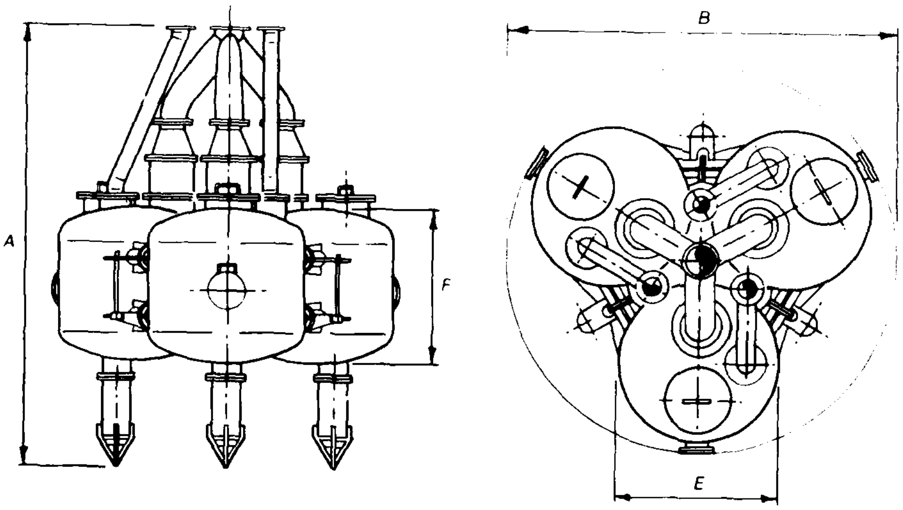
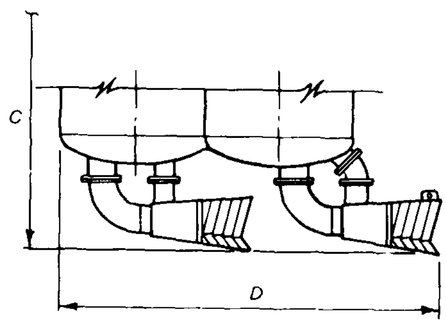


Figure 4. Major components of basic PNEUMA system





DIMENSIONS FT	150 30	300 60	450 80	600 100	1200 150	1500 200
A	12 0	13 4	14 4	14 4	18 7	20 3
B	8 6	10 2	12 2	12 2	15 1	15 1
C	10 5	12 1	13 4	13 8	18 7	20 3
D	9 8	10 8	13 3	13 3	15 9	16 1
E	3 3	3 9	4 9	4 9	5 9	5 9
F	3 9	4 9	4 9	6 6	8 2	9 8
WEIGHT (LB)	6620	9260	12570	14770	24920	28220

Figure 5. Pump body dimensions of standard PNEUMA models

Model 600/100 is one of the larger units, measuring 14.4 ft high by 12.2 ft in diameter and weighing 14,800 lb.

Support Equipment

11. Support equipment was provided by SAW either from inventory or by contract. The major support item needed was a vessel to transport and deploy the pump, air distributor, compressors, and other related items. The vessel used was the *Snell* (Figure 6), a 104-ft-long boat equipped with a 20-ton hydraulic crane. The forward part of the *Snell* is a clear deck which provided space for the pump body, air distributor, air compressors, and discharge piping. A small hold was used to shelter test instruments and electronics. For pumping, the hydraulic crane suspended the PNEUMA pump body over the Snell's port side and raised or lowered it as necessary.

12. At two test sites, it was necessary to transport dredged material to a dumping area. The hopper barge *Currituck* (Figure 7), a

Figure 6. Snag boat Snell

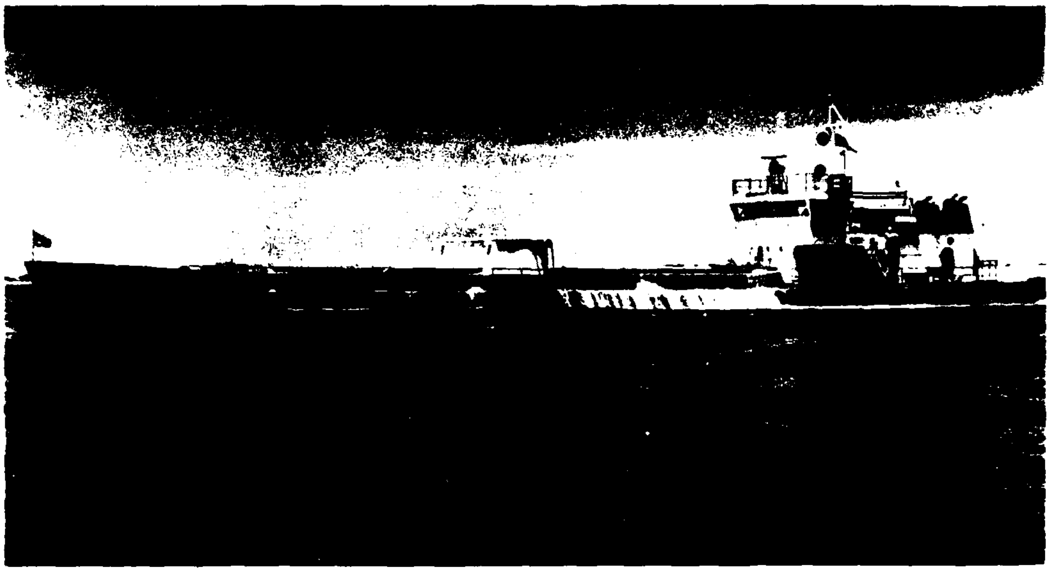


Figure 7. Hopper barge *Currituck*

self-propelled split barge 144 ft long with a hopper capacity of 315 cu yd, was chosen as the transport vessel. During test operations, the *Currituck* laid along the *Snell's* starboard side and received all discharge from the PNEUMA pump. When its hopper was full, the *Currituck* moved to a disposal site and released its load. Testing was suspended until it returned to the *Snell*.

13. Two Joy RPS 1050 units, each mounted on a 4-wheel trailer, supplied compressed air for operating the pump. Each compressor was driven by a diesel engine rated at 288 hp. The units were connected in parallel, so that air supply was a possible maximum 2100 standard cubic feet per minute (scfm) at 100 psi. Some of this air was vented to the atmosphere through a bypass valve prior to reaching the distributor. The system operator adjusted the bypass valve opening based on visual observation of the pump discharge. This technique was a crude way of regulating airflow into the distributor.

Discharge Piping

14. Two discharge piping configurations were used in the test

program. For loading the Currituck, a barge filling arrangement carried discharge across the Snell's deck into the Currituck's hopper through an adjustable loading arm (Figure 8). The vertical loop in the pipeline

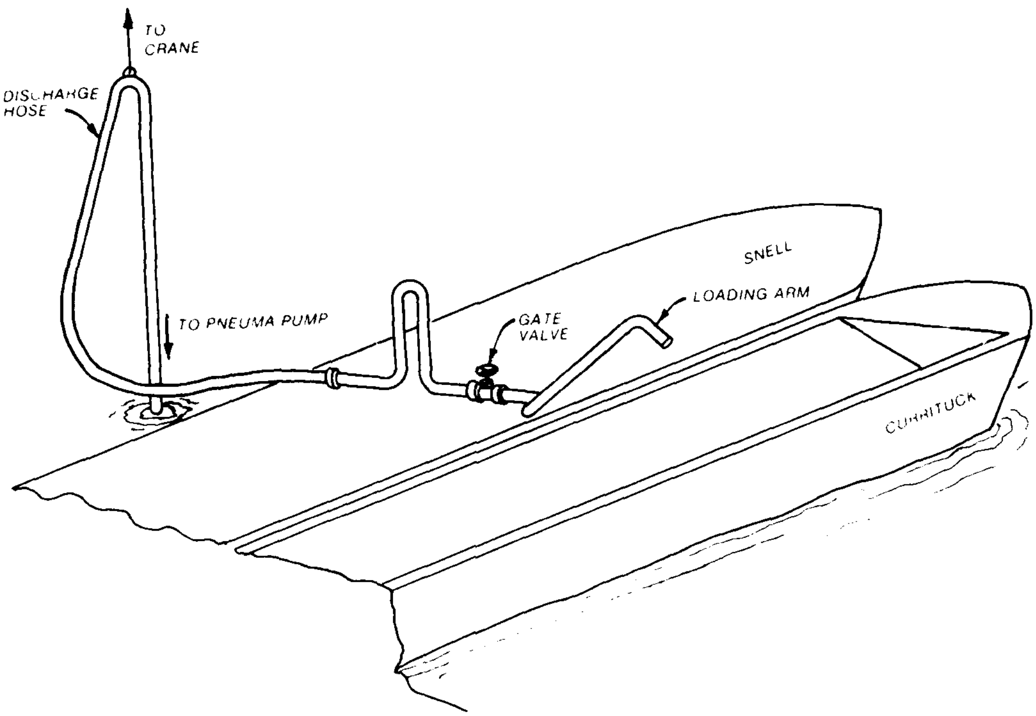


Figure 8. Discharge piping, barge filling configuration

is part of the instrumentation system and will be explained later. The gate valve was used at times to add flow resistance, simulating frictional effects of a longer pipeline. Total pipeline length in the barge filling configuration was 115 ft, consisting of 80 ft of 10-in. flexible rubber hose, 35 ft of 10-in. schedule 40 steel pipe, five 90-deg bends, and two 180-deg bends. The loading arm end was approximately 10 ft above the water surface.

15. For shore discharge, piping on the Snell remained the same as for barge loading, except the loading arm was removed. Pontoon-supported steel pipe and flexible hose ran to shore, where 10-in. steel dredge pipe of varying total length was used.

Instrumentation

16. In evaluating pumping performance, several parameters had to be measured and recorded:

a. Airflow rate supplied to pump.

b. Air pressure.

c. Pressure in discharge pipe at pump body.

d. Flow velocity in discharge pipe.

e. Specific gravity of discharge mixture.

17. Airflow supplied to the pump was measured by an EFM Model VL-45 propeller meter inserted in the 6-in. pipe leading to the air distributor. The meter contains sensors for monitoring air temperature and pressure as well as velocity, so the output can be adjusted to scfm.* Figure 9 shows the airflow meter installed using a 6- × 6- × 3-in. "T" spool section fabricated at WES. Air pressure was measured by two transducers attached to the meter body (Figure 10), one for direct recording and the other as part of the system to give airflow output in scfm.

18. Measuring discharge pressure at the pump body required a submerged pressure transducer with long, damage-prone runs of power and signal conductors. The transducer was installed in a 10-in. stainless steel pipe spool (Figure 11) and was protected from physical damage by a 4-in.-diam pipe housing. The spool was installed just above the junction of the pressure vessel discharge pipes (Figure 12). Steel-armored cable tied to the discharge flexible hoses connected the transducer to its power supply and the recorder. During initial tests, several discharge transducers were damaged, possibly by water hammer caused by the sudden closing of check valves in the discharge outlets. To prevent further damage, a pressure snubbing device was installed between the transducer and discharge pipe. The snubbing device transmits pressure via a number of minute channels, effectively damping high frequency pressure

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* Adjusting an airflow rate to scfm involves converting the measured volumetric flow rate to an equivalent volumetric flow rate at 14.70 psi absolute pressure and 60°F, the conditions for defining a standard cubic foot of air.

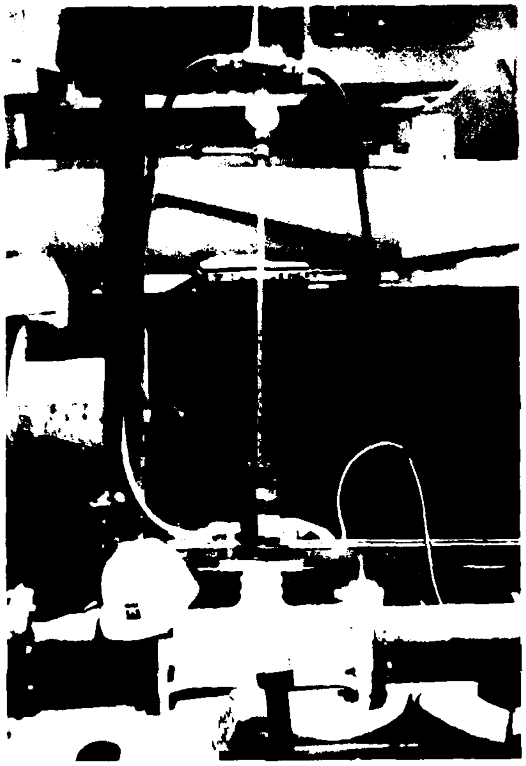

Figure 9. Airflow meter

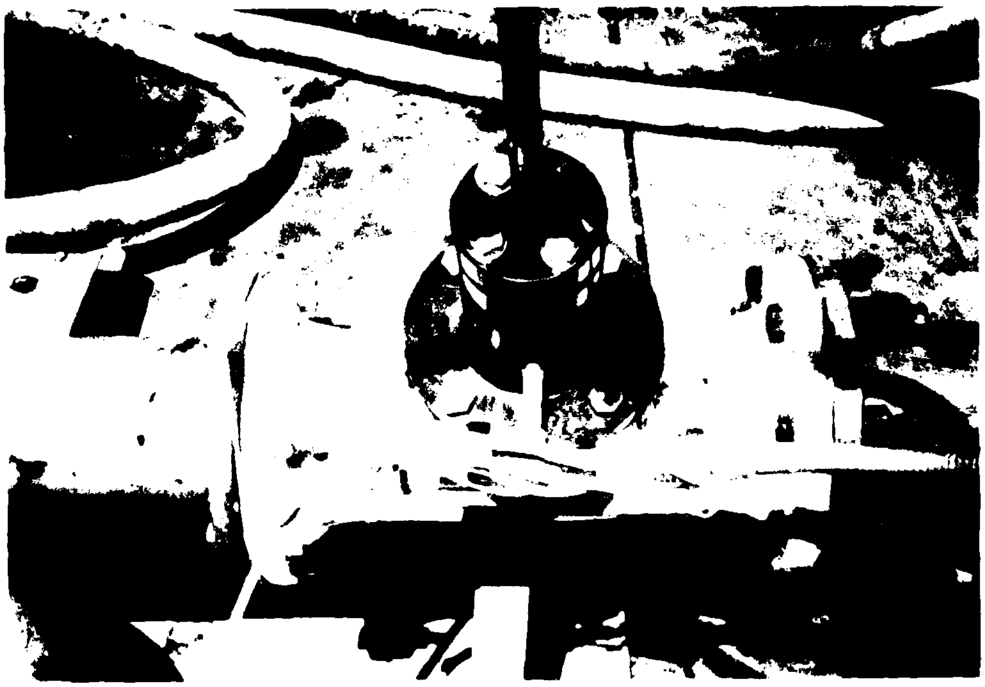

Figure 10. Air pressure transducers

Figure 11. Discharge pressure transducer; pipe spool and housing

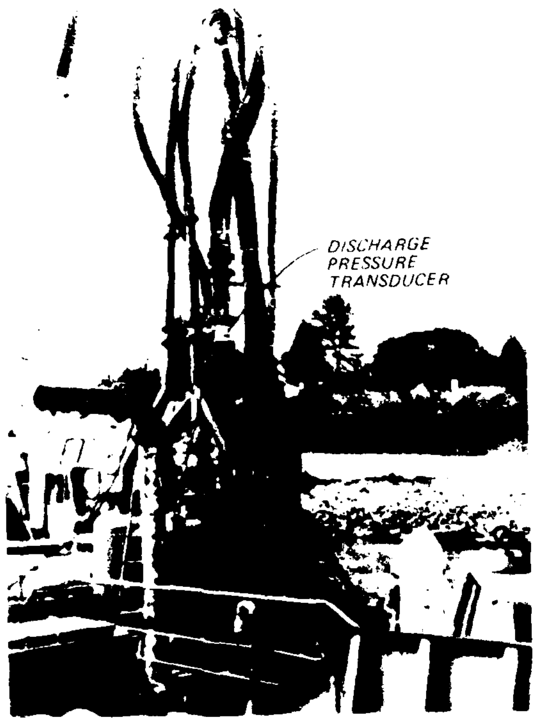

Figure 12. Discharge pressure transducer; installed

variations. Although this protected the transducer from water hammer, it also filtered some pressure variations associated with normal pumping. The result was a "smoothed" pressure reading reflecting only lower frequency changes.

19. Flow velocity in the discharge pipe was measured by a Techsonics Model UFM-PT ultrasonic flowmeter. This device measures flow velocity by the Doppler effect--simply stated, the frequency of sound waves reflected from a moving object will be changed by an amount related to the object's velocity. The Techsonics meter uses a small transducer attached to the discharge pipe to send an ultrasonic signal into the flow stream and receive a reflected signal from particles or bubbles moving with the flow. By comparing transmitted and reflected signals, the particle (flow) velocity can be calculated. The Techsonics meter was mounted on a 10-in. schedule 40 steel pipe measuring section fabricated at WES (Figure 13). Meter electronics are in the box mounted on the right vertical pipe. The transducer is located on the horizontal section at the left, approximately one-eighth of the pipe circumference from the bottom (Figure 14).

20. Specific gravity of the discharge mixture was measured by a Texas Nuclear Corporation Model SG density gage, consisting of a radiation source, a radiation detector, and an electronics package. The source and the detector are mounted on the discharge pipe, while the electronics package can be located remotely. When the meter is calibrated with a liquid of known specific gravity (clear water), the change in radiation passing from the source to the detector can be related to the discharge mixture specific gravity. Due to the random nature of radioactive emissions, an adjustable time constant ranging from [illegible] to 120 sec is needed to produce acceptable precision in the meter reading. Therefore, the meter gives an averaged or smoothed reading of density fluctuations actually occurring in the pipe. Since the PNEUMA pump discharge process is by nature fluctuating, the time constant was kept small so that as much of the fluctuation pattern as possible could be observed. Figure 13 shows the density gage source and detector mounted on the 10-in. test section left vertical pipe. Flow is upward in this pipe,

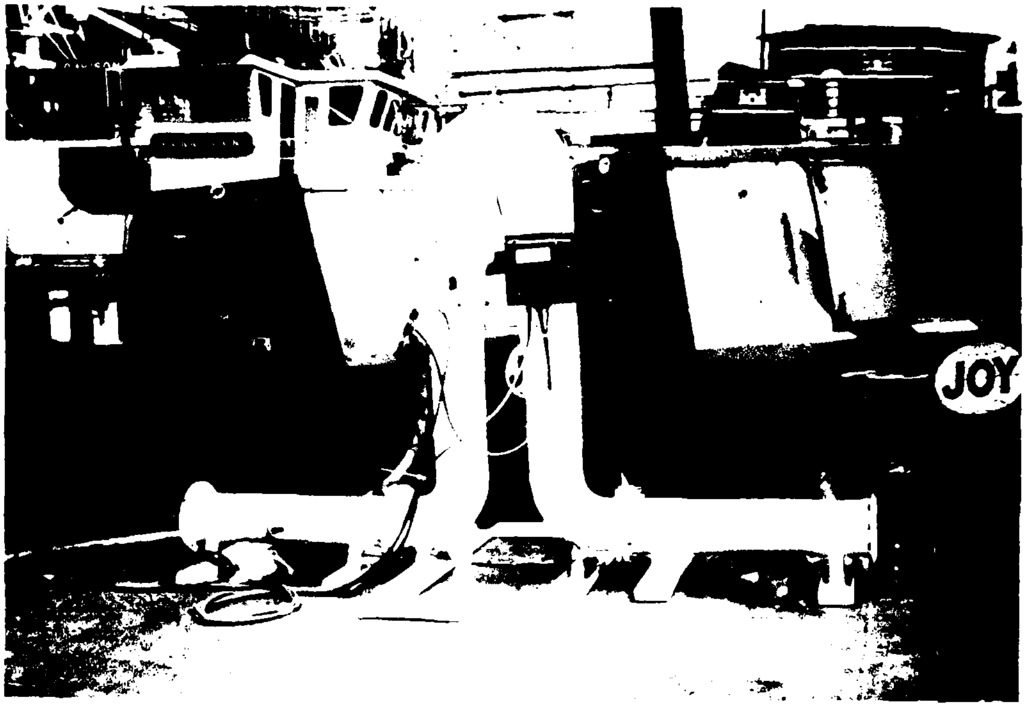

Figure 13. Discharge pipe measuring section

Figure 14. Location of velocity meter transducer

resulting in a more even distribution of sediment over the pipe cross section and increasing meter accuracy. Figure 15 shows the electronics package installed in the *Snell* hold.

21. Signals from the airflow meter, discharge pressure transducer, ultrasonic flowmeter, and density gage were carried by cable to a Honeywell "Electronik 16" multichannel strip chart recorder. This device records sequentially up to 16 different input channels at intervals of 1.67 sec between channels. Six values were recorded:

- a. Airflow rate, scfm.
- b. Air pressure, psig.
- c. Discharge pressure, psig.
- d. Discharge velocity, fps.
- e. Discharge specific gravity.
- f. Excavation rate, cu yd/min.

The excavation rate recorded was not a true in situ excavation rate. It was derived electronically by combining velocity and density meter

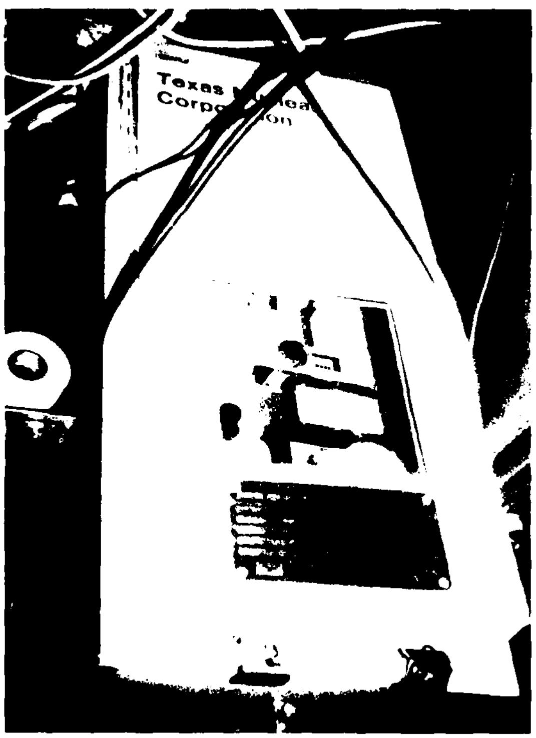

Figure 15. Density gage electronics

readings and assuming the same in situ solids content for all material dredged. It was used only during testing to indicate relative pump performance. Excavation rates described later in this report are calculated values using more precise sediment information.

22. Each of the six input channels was sampled discretely every 10.0 sec; however, the samples were not taken at the same time. The recorder sampled channel a, then b, then c, etc., with 1.67 sec elapsing between samples. The total interval between subsequent samples of each channel was 6 × 1.67 = 10.0 sec. Understanding this data recording procedure is essential to later explanations of data reduction methods.

23. Two input channels were also recorded continuously on Rustrak strip chart recorders. Usually, discharge specific gravity and either discharge pressure or velocity were recorded. Figure 16 shows the total

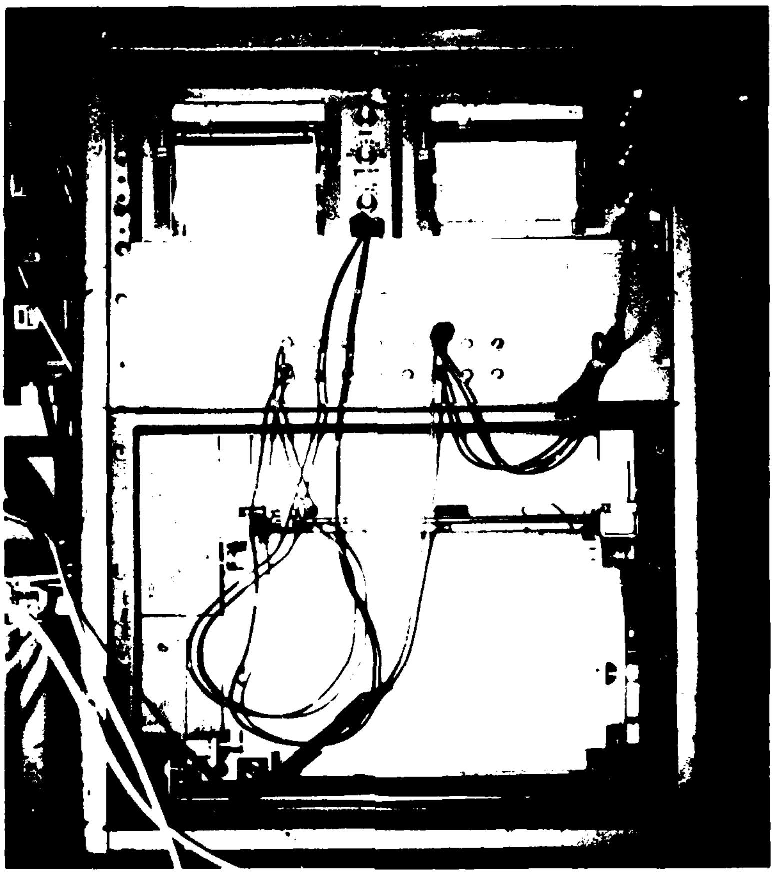

Figure 16. Multichannel and single-channel recorders

recording package, with the multichannel recorder on bottom and two single-channel recorders on top.

24. In addition to monitoring pumping performance, turbidity generated by the pump in loose, fine-grained sediments was evaluated at one site. Water samples taken downstream of the pump were analyzed for total suspended solids and turbidity by Law and Company of Wilmington, North Carolina. Suspended solids were determined by drawing each sample through a 0.45-μ filter, following the procedure outlined by the American Public Health Association.* Sample turbidity was determined in Nephelometric Turbidity Units (NTU) using a Turner Fluorometer with two 2812 Filters to correct for fluorescence. Samples were collected simultaneously at depths of 0, 5, 10, and 15 ft using two pump racks (Figure 17)

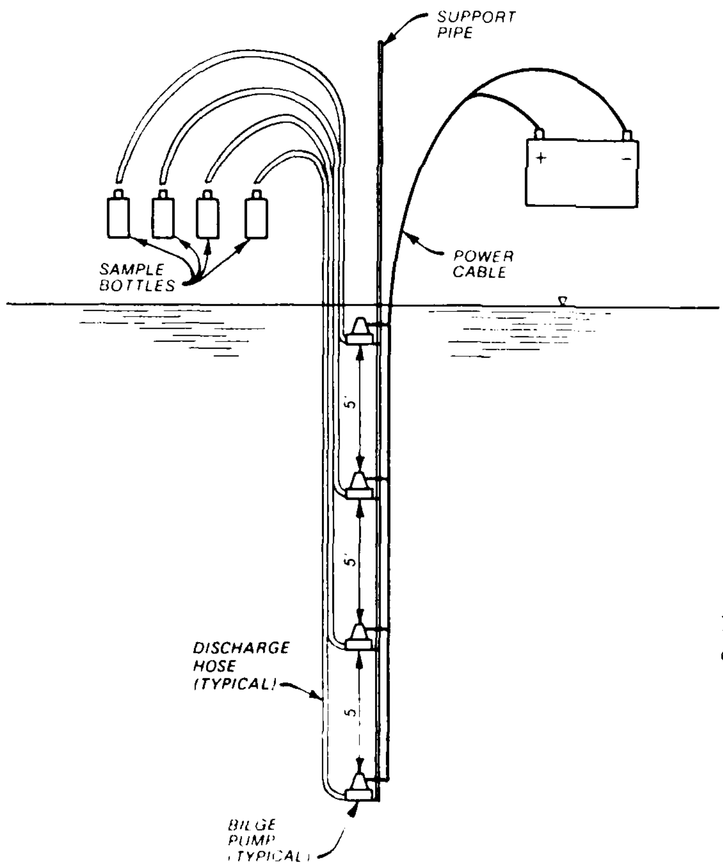

Figure 17. Schematic of turbidity monitoring pump rack

* American Public Health Association. 1971. "Standard Methods for the Examination of Water and Wastewater," Washington, D. C.

with four marine bilge pumps mounted at 5-ft intervals. Discharge from each bilge pump was collected in a sample bottle. Each sample was refrigerated and delivered to the laboratory the same day.

Test Program

25. Testing was conducted at four different locations:

   a. Cape Fear River at Wilmington, North Carolina, near the U. S. Highway 17 Bridge adjacent to the SAW Engineer Yard.

   b. Lock and Dam No. 1 on the Cape Fear River midway between Riegelwood and Carvers, North Carolina.

   c. Masonboro Inlet, located at the south end of Wrightsville Beach, North Carolina, connecting Middle Sound to Onslow Bay.

   d. Military Ocean Terminal at Sunny Point (MOTSU), located along the Cape Fear River 8 to 11 miles from the mouth.

26. Location b provided testing in a lock and dam approach; location c, a tidal inlet; and location d, a dock area. Location a was used only for pumping water at the start of the test program, to check pump and instrument operation and collect baseline pumping data.

27. Figure 18 shows a plan view of Lock and Dam No. 1 and the general test area. Sediments at this location were tan fine to medium sand, unit weight 131.7 lb/cu ft (bulk specific gravity 2.11) and median diameter of 0.6 mm.* Depths in the downstream lock approach were 6.0 to 11.0 ft or more, with a noticeable shoal at the approach entrance. One of the main reasons for using this site, which presented difficulties in transporting the pump and personnel, was to test the manufacturer's claim that the pump could dredge in confined areas around structures. Figure 19 shows the lock approach from downstream, with a guide bulkhead on the right and fendering dolphins on the left. The *Currituck* received and disposed of dredged material at this site.

* D'Appolonia Consulting Engineers, Inc. 1978. "Sediment Samples, Grain-Size Analyses and Unit Weight Determinations, Bottom Sediment Samples; Experimental Dredge Project," Letter Report, Project No. SE78-756, Wilmington, N. C.

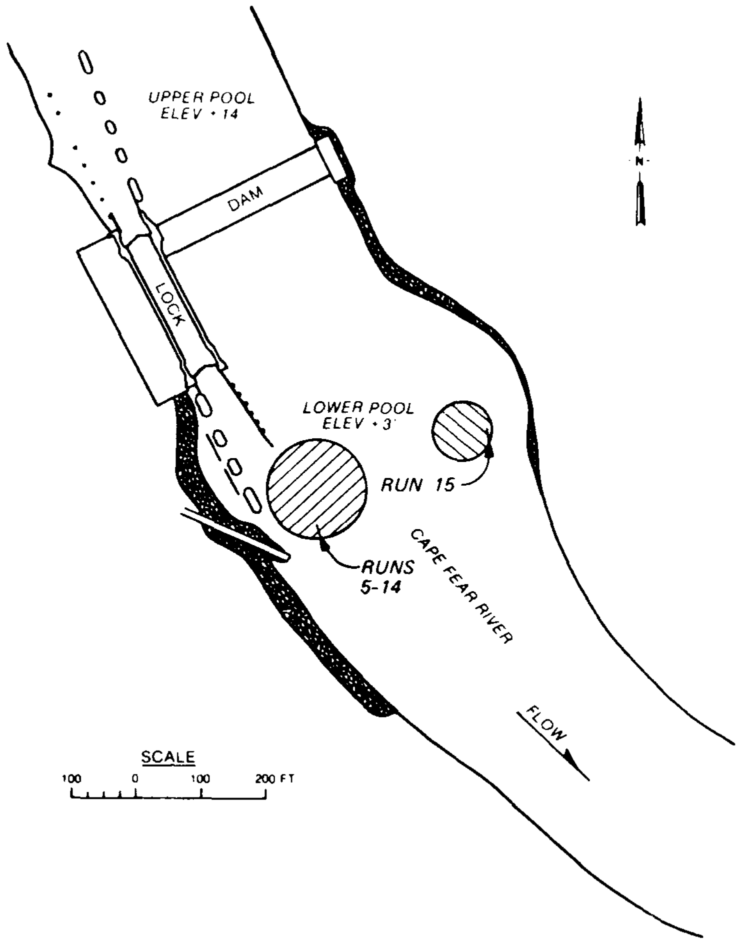

Figure 18. Lock and Dam No. 1

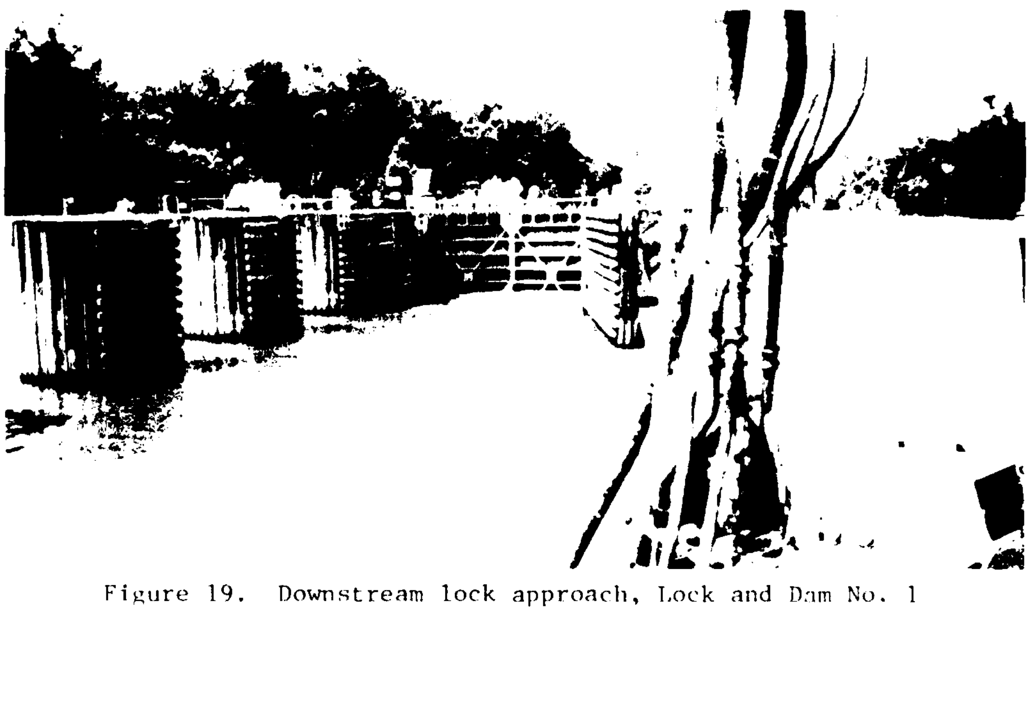

Figure 19. Downstream lock approach, Lock and Dam No. 1

28. Masonboro Inlet is shown in Figure 20, including the test area and the approximate discharge pipe route. Total length of the discharge pipe was usually 2000 ft, but tests were made at lengths of 1520, 740, and 420 ft for comparison purposes. Material dredged at Masonboro, as described by D'Appolonia, Inc., was tan fine to coarse sand with traces of shell fragments. In situ unit weight was 125.5 lb/cu ft (specific gravity 2.01) and median grain size was 0.4 mm. The main purposes of testing at Masonboro Inlet were to obtain data on the pump discharging through a pipeline and to determine performance in typical tidal inlet conditions. Experience using the pump in wave action was not obtained for the following reasons:

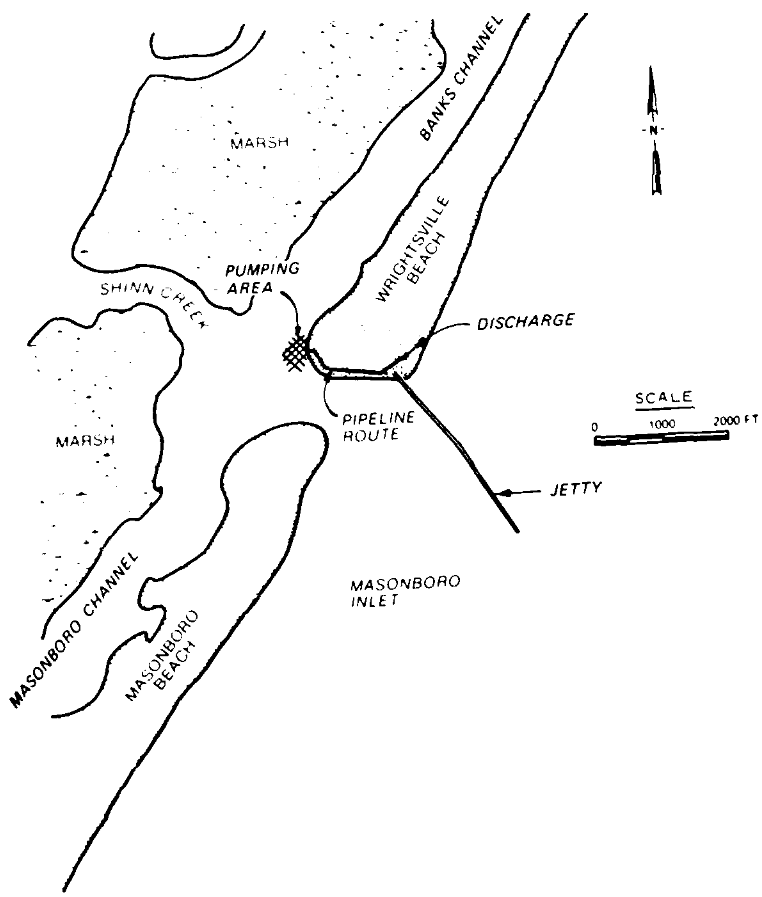

Figure 20. Masonboro Inlet

a. The pumping area was relatively sheltered. No significant waves were experienced during testing.

b. The method of deploying the PNEUMA pump (over the side of the Snell suspended from a crane) was not suited for wave conditions. The Snell's deck was crowded with equipment, and a moving deck and swinging pump would have been hazardous.

Depths in the pumping area at Masonboro Inlet ranged from 10 to 15 ft below mean low water before pumping. This provided an opportunity for pumping sand at deeper depths than at Lock and Dam No. 1. Since the PNEUMA pump depends on ambient water pressure to fill the pressure vessels, a depth increase in shallow water should help the pump's excavating ability.

29. Figure 21 shows the area around Wharf No. 3 at MOTSU. A large pumping area was needed at this site, since the pump had to be moved along the bottom to dredge the fine-grained sediment there. Describing this sediment is more complicated than for the other two test

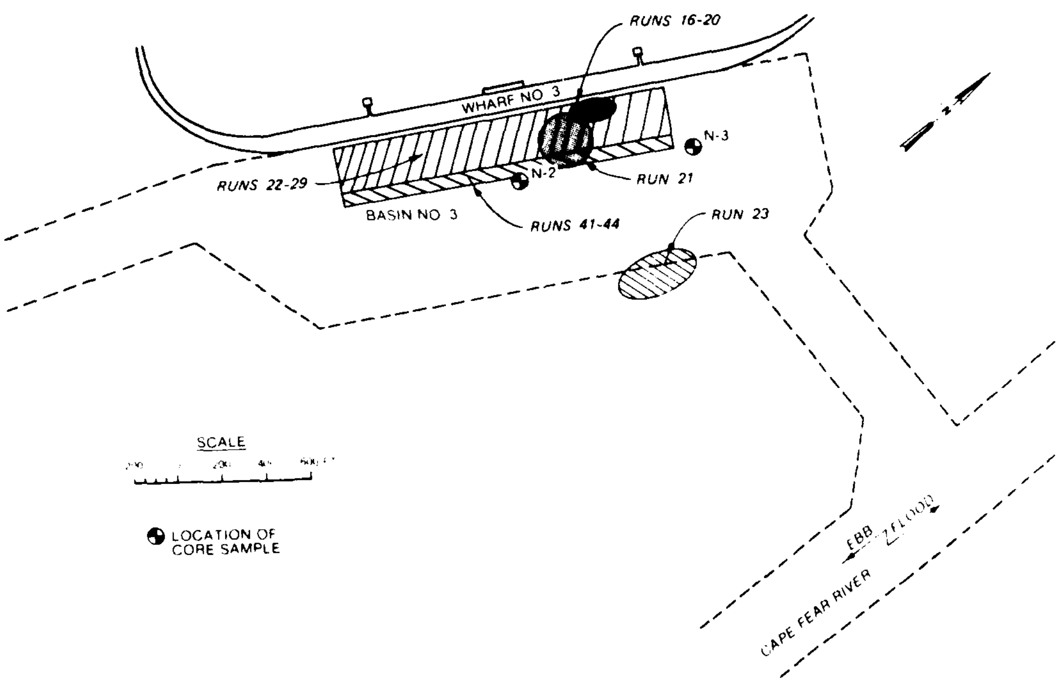

Figure 21. Wharf No. 3, MOTSU

sites. D'Appolonia, Inc., characterized it from one grab sample as a dark gray and black silty clay, in situ unit weight 70.6 lb/cu ft. A more complete analysis was conducted in 1979* in conjunction with hydraulic modeling of the MOTSU area. This analysis showed that the Wharf No. 3 ship basin bottom consisted of silt and clay mixed with 10 to 15 percent organic material. This sediment moves down the Cape Fear River and settles in the relatively still ship basins at MOTSU. This depositional process results in a density increasing with depth in the sediment, as the sediment consolidates with time. Figure 22 shows this variation in two core samples located as shown in Figure 21. Divers taking the samples reported a layer of low density "fluff" mud 8 to 10 in. thick. This layer had consolidated in the samples to about 4 in. by the time they were analyzed. Therefore, upper sediment in the field is probably even less dense than that shown in Figure 22. Obviously, any value of in situ unit weight assigned to the MOTSU sediment has to be an average. Therefore, depth-averaged unit weights were calculated for each sample in Figure 22 down to 2.5 ft. The arithmetic average of these two weights, 76.8 lb/cu ft (specific gravity 1.23), is used in this report as the MOTSU sediment unit weight. Later in this report, calculations such as the in situ excavation rate are made using this assumed unit weight. This is important to remember, since at times the PNEUMA pump was obviously digging material denser than the assumed value. In such cases, the calculated excavation rate was higher than actual. Conversely, when the pump was digging a lighter material, the calculated rate was less than actual. Depths in the pumping area at MOTSU ranged from 12 to 35 ft, providing the possibility for comparing performance versus depth. The purposes of testing at MOTSU were to gather performance data in fine-grained sediments, evaluate the PNEUMA system for dredging next to wharfs and piers, and study turbidity generated by the pump in fine-grained sediment. Material dredged at MOTSU was discharged into the Currituck.

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* Soil & Material Engineers, Inc. 1979. "Sediment Analysis, Military Ocean Terminal at Sunny Point, Southport, North Carolina," Letter Report, DACW 54-79-M-1298, Raleigh, N. C.

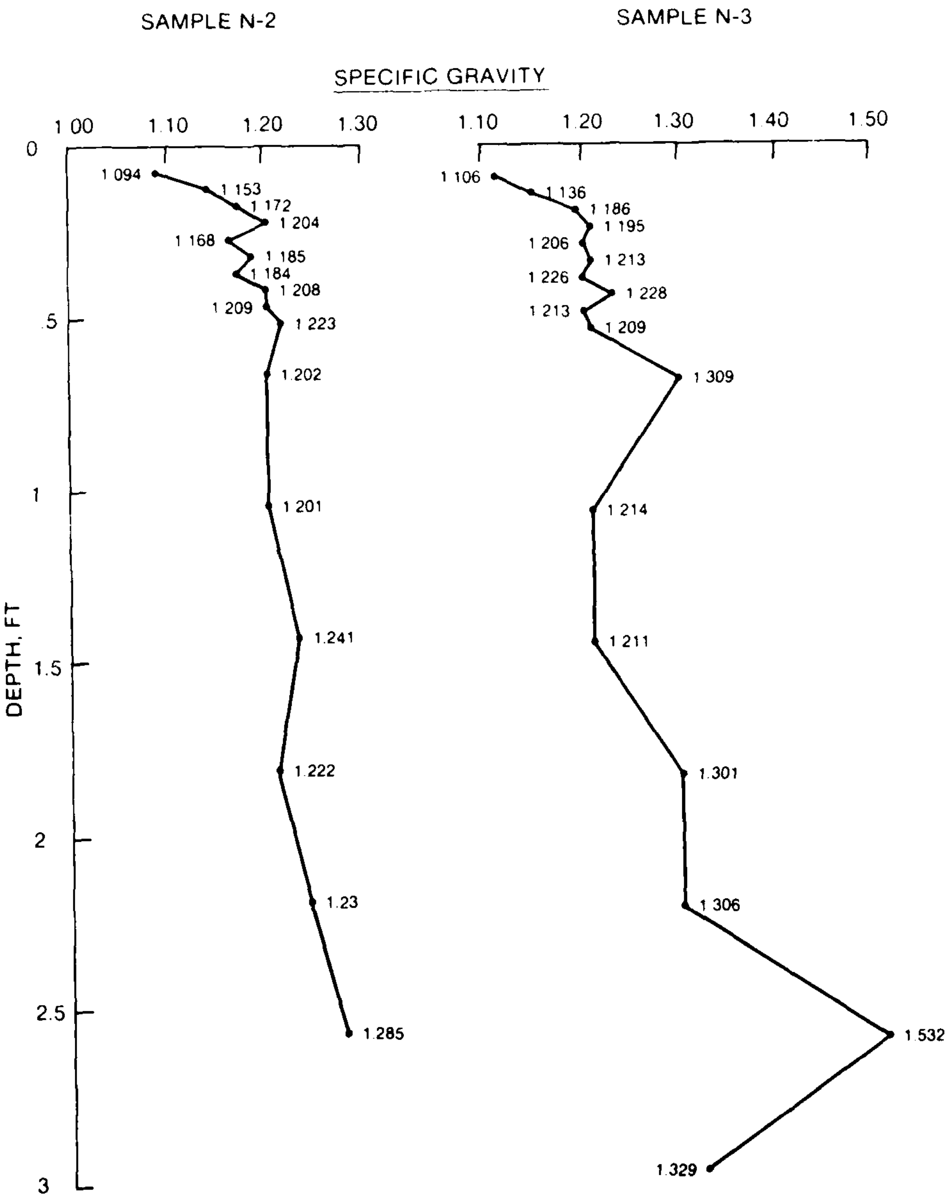

Figure 22. Typical sediment density profiles, MOTSU

30. Data were collected at each test site in a series of pumping runs, each run lasting from 30 to 300 min. Runs for the entire program were numbered 1 through 44 in chronological order. In reducing the data, longer runs were sometimes subdivided or else only portions of a run were used. These subdivisions are called segments, and each run may contain up to three. Thus, a particular record of continuous data might be referred to as Run No. 19, Segment 1. Table 1 summarizes the testing program chronology:

Table 1

Chronology of Testing Program

Year 1978			
From	To	Location	Run No.
14 Aug	23 Aug	Engineer Yard	1-4
24 Aug	31 Aug	Lock and Dam No. 1	5-15
5 Sep	18 Sep	MOTSU	16-29 (turbidity tests on runs 21-23)
19 Sep	29 Sep	Masonboro Inlet	30-40
4 Oct	5 Oct	MOTSU	41-44

PART III: TEST RESULTS

Data Reduction and Presentation

31. Plate 1 is a flow chart outlining the process of data collection, reduction, and presentation used in this study. Sections dealing with measuring instruments, parameters measured, and recorders have already been discussed. Data reduction and formats used in presenting data will now be described.

Treatment of raw data

32. Reduction of data recorded on the multichannel recorder began with transcribing the data into a form suitable for automatic data processing (ADP). This was accomplished by means of a digitizer table equipped with a movable cursor, the position of which can be determined in X-Y coordinates by pushing a button. By tracing plots of the six recorded parameters with the cursor, parameter values versus time were transferred in digital form to magnetic tape.

33. Three raw data channels (airflow, discharge velocity, and discharge specific gravity) were plotted versus time directly from the raw data tape. These plots are shown in Appendix A, grouped by run and and segment numbers. If data were not taken for a certain channel, as in the case of discharge specific gravity for water pumping tests at the Engineer Yard, "NO DATA" appears in the plot space.

Basic data reduction

34. Data are also presented as histograms of calculated parameter values versus percent occurrence. Data for calculating these histograms were chosen from time periods when discharge specific gravity was predominantly greater than a specified threshold value. The threshold value used was 1.10 for fine-grained sediment and 1.20 for sand. For example, looking at the discharge specific gravity plot for run 11, segment 2 (Plate A12), the time period from 21 to 44 min was chosen for calculating histograms. A histogram was computed by counting the number of data points which fell in each of several value classes, then dividing these counts by the total number of data points in the time period,

giving a percentage. For some runs and segments, several time periods were chosen and combined. For example, for run 33, segment 1 (Plate A24), data in the time periods of 5 to 19 min and 31 to 43 min were combined to calculate one histogram. Some runs did not achieve sufficiently high specific gravities to warrant histogram calculations. Table 2 lists the time periods used for histogram calculation for each run and segment and the histogram plate number in Appendix A. Times are given in multiples of 0.15 min to correspond with interpolated data time-steps, which will be described in succeeding paragraphs.

35. Histograms for two different calculated parameters were prepared for each applicable run and segment. The first type gives discharge percent solids in class intervals of 5 percent. Data for this histogram came from the raw data tape. A simple calculation requiring sediment solids density produces values of discharge percent solids by volume. Equations used for this data reduction process are described in Appendix A.

36. The second type of histogram shows calculated excavation rates. This histogram as well as the remainder of data output, required further manipulation of raw data. The first step was to calculate measured parameter values that coincided in time. As described earlier, data points collected in the field were not synoptic, but spaced at intervals of 1.67 sec between parameters and 10 sec between successive values of the same parameter. To perform calculations involving more than one parameter, parameter values must coincide in time. This was accomplished by a computer program which calculated at intervals of 0.15 min values of all measured parameters (except estimated excavation rate) and discharge percent solids, based on linear interpolation between adjacent raw data values. Output from this program was a magnetic tape of interpolated data for airflow rate, air pressure, discharge pressure, discharge flow velocity, discharge specific gravity, and discharge percent solids. These data were used in a calculation program together with the sediment in situ percent solids, discharge pipe size, and relation of airflow to horsepower to produce the following calculated parameters:

Table 2

Time Periods for Histogram Calculation

Run No.	Segment No.	Time Period, min From	To	Plate No.
1	1	No histograms		--
2	1			--
3	1			--
5	1			--
6	1			--
10	1	0.00 9.30	2.10 14.25	A7
10	2	No histograms		
10	3	No histograms		
11	1	4.80	13.05	A11
11	2	21.45	44.25	A13
12	1	0.00	5.25	A15
13	1	No histograms		
14	1	No histograms		
15	1	No histograms		
16	1	36.30	46.05	A53
19	1	No histograms		
19	2	21.15	27.15	A56
19	3	No histograms		
20	1	21.15 37.45	24.45 39.75	A59
20	2	2.40 42.75	16.95 45.00	A61
21	1	25.95 33.15 52.65	28.35 37.20 54.30	A63
22	1	28.65	43.05	A65
22	2	5.25 14.55	10.65 16.05	A67
23	1	No histograms		
23	2	6.30 34.35	9.75 37.65	A70
26	1	32.70	44.10	A72
26	2	10.80	34.95	A74
27	1	No histograms		
27	2	0.00	25.95	A77

(Continued)

Table 2 (Concluded)

Run No.	Segment No.	Time Period, min		Plate No.
		From	To	
28	1	No histograms		
28	2	21.75	36.45	A80
30	1	No histograms		
31	1	No histograms		
32	1	No histograms		
32	2	21.45	33.90	A23
33	1	5.10 31.35	18.90 42.60	A25
33	2	No histograms		
34	1	7.35	18.00	A28
34	2	No histograms		
34	3			
35	1			
35	2			
36	1	26.10	37.35	A34
36	2	0.00 22.20	17.40 45.60	A36
37	1	23.10	37.80	A38
37	2	4.05 25.35	19.95 38.25	A40
37	3	6.75	24.30	A42
38	1	No histograms		
38	2	No histograms		
38	3	No histograms		
39	1	29.55	41.40	A47
40	1	38.55	48.00	A49
40	2	0.00	10.35	A51
41	1	0.00	6.15	A82
41	2	No histograms		
41	3	No histograms		
42	1	7.20 34.20	16.20 41.10	A86
43	1	No histograms		
43	2	17.10	21.45	A89
44	1	5.95	13.65	A91
44	2	10.05 26.55 49.80	14.70 41.10 55.05	A93

a. Discharge flow, gpm.

b. In situ excavation rate, cu yd/hr.

c. Total discharge head, feet of water.

d. Pump input horsepower.

e. Pump output horsepower.

f. Pump efficiency.

Presentation of data

37. The interpolated data and calculated parameters given above are listed in tabular form in Appendix C. At the beginning of each listing is the test location, date, run and segment numbers, average water depth, type of material pumped, in situ percent solids, and discharge line length. When the pump discharged into the Currituck, the discharge line was as shown in Figure 8, referred to in Appendix C as the "barge filling configuration."

38. In looking at Appendix C, the reader should keep in mind that values given are either interpolated or calculated from interpolated data. In this type of data reduction, occasionally values are calculated which are obviously incorrect. Most of these incorrect values can be traced to the fact that data channels were nonsynoptic, as previously discussed. Many incorrect values were eliminated in the calculation program, but it is important that values be considered in relation to surrounding values and trend(s) that they exhibit. This is especially important for discharge pressure and specific gravity, which were measured in a more time-averaged, slowly varying manner than other parameters. Values calculated using time-averaged parameters, i.e., discharge percent solids, in situ excavation rate, pump output horsepower, and pump efficiency, should be reviewed in a similar manner.

Interpretation of Water Test Data

39. Three water pumping runs were conducted in the Cape Fear River near the SAW Engineer Yard and one near Lock and Dam No. 1. Results of runs 1, 2, and 3 are presented, but the discharge pressure transducer failed during run 4, making that run worth little for information purposes.

40. During each run, a 10-in. gate valve on the discharge line was closed in steps until it was about three-fourths closed. This was done to produce increased discharge resistance and observe resistance effects on pump operation. The runs were conducted at 10-, 20-, and 30-ft depths to observe depth effects on the pump.

Discharge velocity

41. Maximum sustained discharge velocities during runs 2 and 3 ranged from 13.5 to 14.0 fps, corresponding to flows of 3300 to 3500 gpm. For run 1, maximum sustained velocity was approximately 10.5 fps. The effect of closing the discharge gate valve in steps is evident in plots of discharge velocity versus time. Beginning at 20.0 min in run 1 (Plate A1), 15.0 min in run 2 (Plate A2), and 10.0 min in run 3 (Plate A3), discharge velocity decreases in steps corresponding to incremental gate valve closing. At the end of each run, the gate valve was opened completely and discharge velocity returned to its beginning value or higher.

Airflow rate

42. The airflow rate for each run showed no discernible variation corresponding to variations in discharge velocity. For each run, after some initial adjustments the airflow rate reached and maintained a relatively steady value. Figure 23 shows a plot of these values versus water depth for runs 2 and 3. This figure also shows required air compressor horsepower, based on Equation A5 in Appendix A. The validity of approximating airflow versus depth as a straight line for a constant pump discharge is also discussed in Appendix A. Figure 23 is important because it points out a fundamental difference between the PNEUMA pump and a centrifugal or piston-type pump; i.e., the horsepower required to produce a given discharge varies directly as water depth over the PNEUMA pump, all other factors being the same. As discussed in Appendix A, the PNEUMA pump is driven by a highly compressible "piston" (air) but still must operate on the positive-displacement principle. As water depth is increased, more air in terms of scfm must be provided to produce the same displacement volume and, hence, the same discharge. Air must also provide additional power to raise the discharge slurry in the

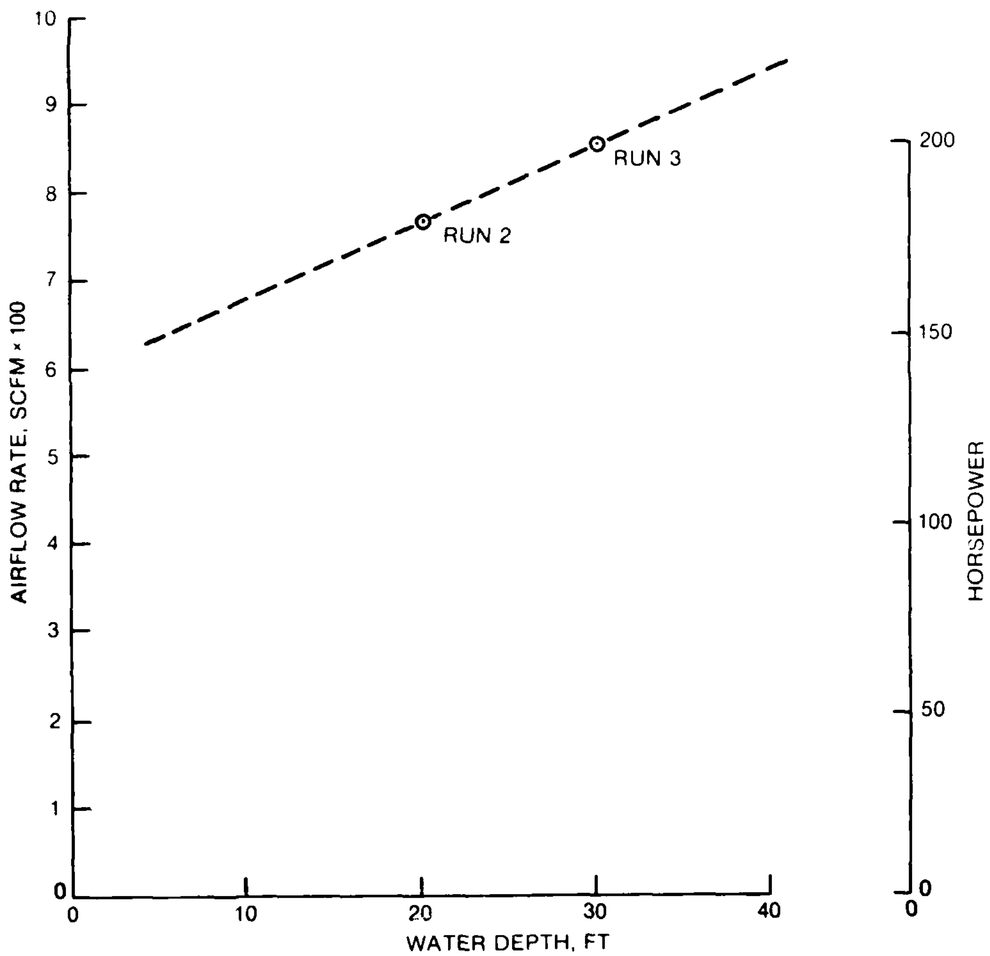

Figure 23. Airflow versus depth, runs 2 and 3, constant pump output, water tests

water column and to overcome increased resistance caused by a longer discharge line, although these effects are several orders of magnitude smaller. By comparison, a submerged centrifugal or piston pump would be affected by increasing depth only by increased resistance in a longer discharge line and by having to raise the discharge slurry higher.

Efficiency

43. Another characteristic of the PNEUMA pump evident from Appendix C data is its inefficiency as a pumping device compared with a centrifugal or piston pump. Pump efficiency is usually defined as the

ratio of output to input horsepower for a given situation. When pumping water, a centrifugal or piston pump can usually give 80 percent efficiency or better. By contrast, as shown in Appendix C, the PNEUMA pump in runs 1, 2, and 3 ranged mostly from 8 to 12 percent efficiency. While these figures may have been affected by data interpolation and damped discharge pressure measurements discussed earlier, it is clear that the PNEUMA pump is much less efficient than a centrifugal or piston pump in water. However, if the PNEUMA pump can perform tasks not achievable by other pumps, efficiency becomes less relevant.

Interpretation of Sand Test Data

44. Sand was pumped at two different locations: Lock and Dam No. 1 and Masonboro Inlet. For discussion purposes, runs from these sites will be considered together. Differences attributable to site alone will be noted.

Discharge specific gravity

45. Looking at the Appendix A plots of discharge specific gravity, several points can be noted. First, the plots are often erratic. There are several possible causes for this behavior, most of them related to operation and performance of the PNEUMA pump. The first cause of erratic specific gravity readings is air in the discharge line, which causes tremendous variations in density "seen" by the nuclear density meter. Referring to Figure 2, if material in a pressure vessel is forced out and air is still supplied to the vessel, air can enter the discharge line. This situation can occur continually due to improper regulation of the air supply system or intermittently when a pressure vessel does not fill properly. In runs 5 and 6, too much air was fed continually to the pressure vessels. At times in other runs, the situation occurred intermittently due to pressure vessels filling incompletely or with material more easily forced out. Air in the discharge is easily verifiable, since it is apparent to an observer at the discharge end.

46. Another cause of erratic specific gravity readings is variation in the pumped material. If this variation is large enough, it can

let air into the discharge line as discussed above. However, the condition does not have to be that severe to cause a noticeable effect. Material in the PNEUMA discharge line may be thought of as a series of slugs, each slug representing the contents of one pressure vessel. Variations in the contents of different vessels, or the same vessel at different times, could cause differences in the average specific gravity of each slug. Consequently, the nuclear density meter reading will vary. As further clarification, consider the following:

> The volume of a pressure vessel for a PNEUMA 600/100 pump is approximately 100 ft^3.* Assume that 75 percent of this volume, or 75 ft^3, is forced into the discharge line in each cycle at an average velocity of 10 fps. Then, in a 10-in. discharge pipe, it would take approximately 14 sec for the contents of one vessel to pass the nuclear density meter. Therefore, variations in pressure vessel contents would cause changes in discharge specific gravity at least every 14 sec.

47. The situation of "slug flow" in the discharge line is complicated further by the fact that density may vary not only between slugs but also within each slug. This would be true especially in coarser material such as sand, where rapid solids settling would occur in the pressure vessel. This settling would result in a stratified mixture in the vessel, varying from more dense at the bottom to less dense at the top. In some cases, solids may settle out completely, leaving a layer of saturated solids at the vessel bottom covered by water. Relative thickness of the two layers would probably vary between fillings, depending upon sediment intake conditions. Referring to Figure 24, when this stratified mixture is forced out of the vessel, denser material would go first, followed by less dense upper layer(s). The result would be a density gradient within each slug and possibly a sharp density change between slugs, as illustrated in Figure 25.

48. Variation in material pumped is evident from Figure 26, which shows portions of the continuous discharge specific gravity recording made during run 37, segment 1. Times on this figure correspond to times

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* Source: conversation with PNEUMA North America.

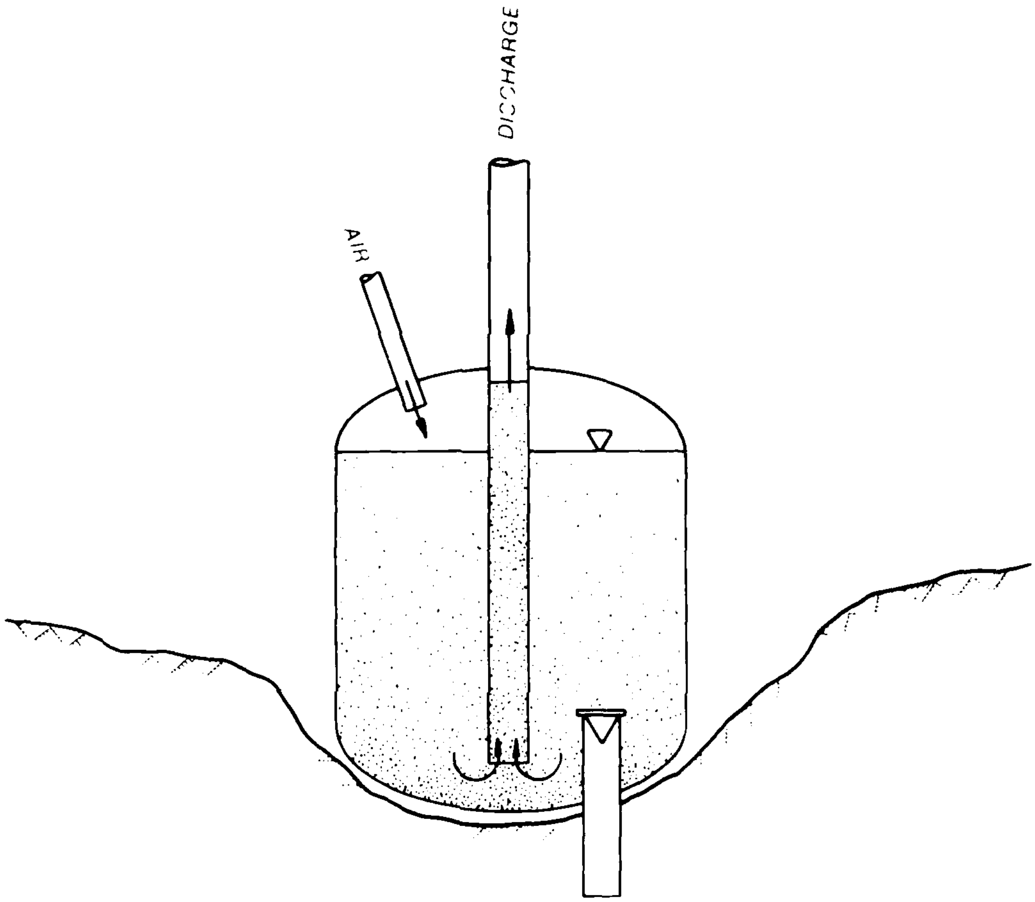


Figure 24. Hypothetical density gradient in PNEUMA pressure vessel for coarse material

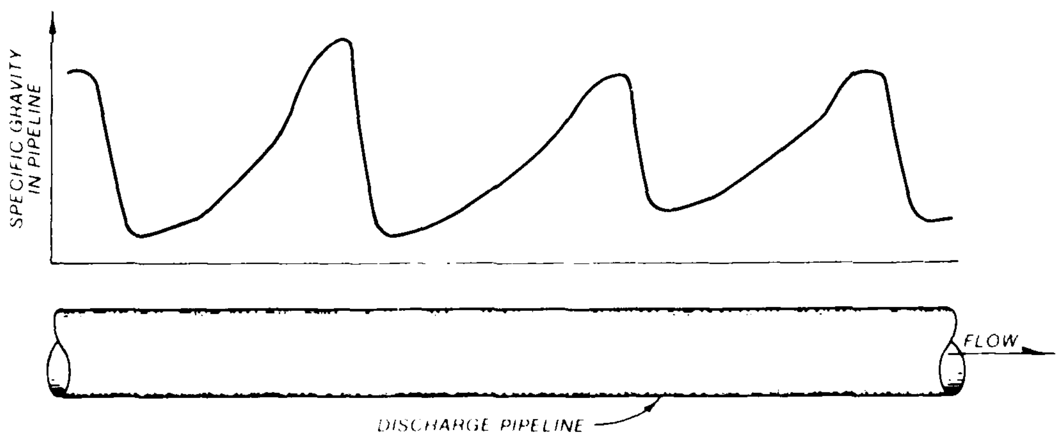
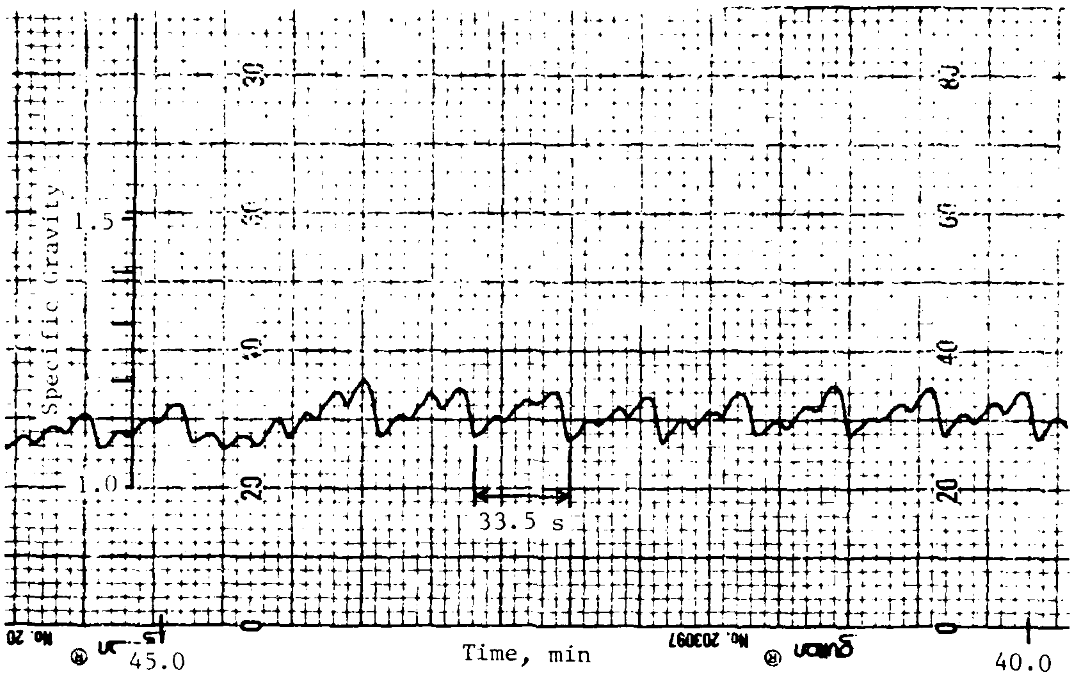


Figure 25. Hypothetical density values in PNEUMA discharge line



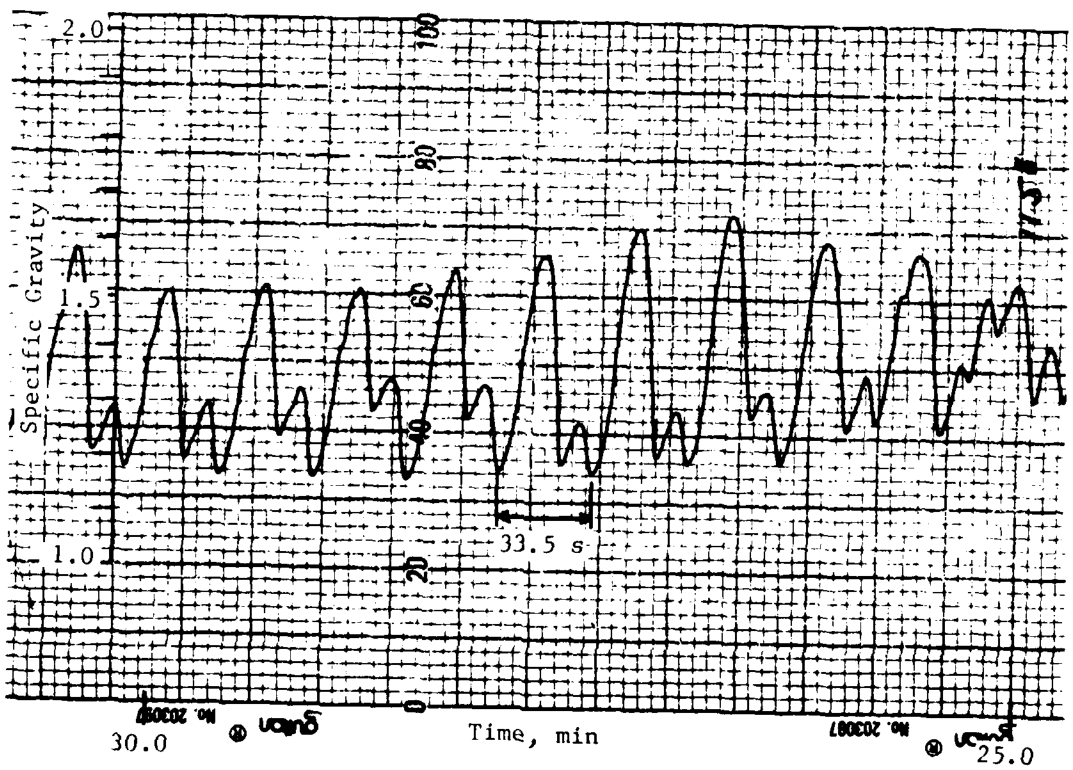


Figure 26. Discharge specific gravity, run 37, segment 1, sand tests

on Appendix A plots (Plate A37). Between 40.0 and 45.0 min, the density gage output varied periodically between 1.10 and 1.20. The period of these variations is approximately 33.5 sec, which was the time required for a complete pumpout cycle of all three pressure vessels. Within a cycle, each vessel's contribution is as shown by a distinct, equally spaced peak in the record. Each peak has a different value, indicating unequal discharges from the three vessels. The value of each peak in successive cycles is approximately the same, showing the phenomenon is regular and repeatable. A more radical example of this behavior is shown in the period 25.0 to 30.0 min. Here, the difference between one vessel and the other two is quite large. Each cycle has two peaks--one in the 1.2 to 1.4 range, the other in the 1.5 to 1.7 range. The higher peak appears to represent the output of two vessels, while the smaller one covers the third.

49. Figure 27, which displays portions of the same record shown in Figure 26, provides some evidence of density variations during the discharging of one pressure vessel. Two distinct perturbations appear in the record in the period from 21.8 to 22.0 min, which is approximately the time required for pumpout of one vessel. The record to the right of this period shows more perturbations, although some of these may be due to the low discharge specific gravity. Since the minimum density gage time constant (5 sec) is almost half the pumpout time for one vessel, real density variations represented by these perturbations may be much larger. An illustrative example is shown in Figure 28. The upper plot in this figure is a simple assumed behavior of discharge specific gravity. The lower is a time-averaged plot of the upper using a 5-sec time constant. (The time constant algorithm used by the density gage is more complicated than the simple averaging employed in Figure 28. However, the figure serves to explain a principle.) The effect of a single perturbation is shown by the dotted line in each plot. The time-averaged plot without the perturbation has a smoother shape than the instantaneous. The quick rise of specific gravity is replaced by a gradual rise to a lower maximum which occurs several seconds later. The perturbation is lost almost completely in the time-averaged plot, except

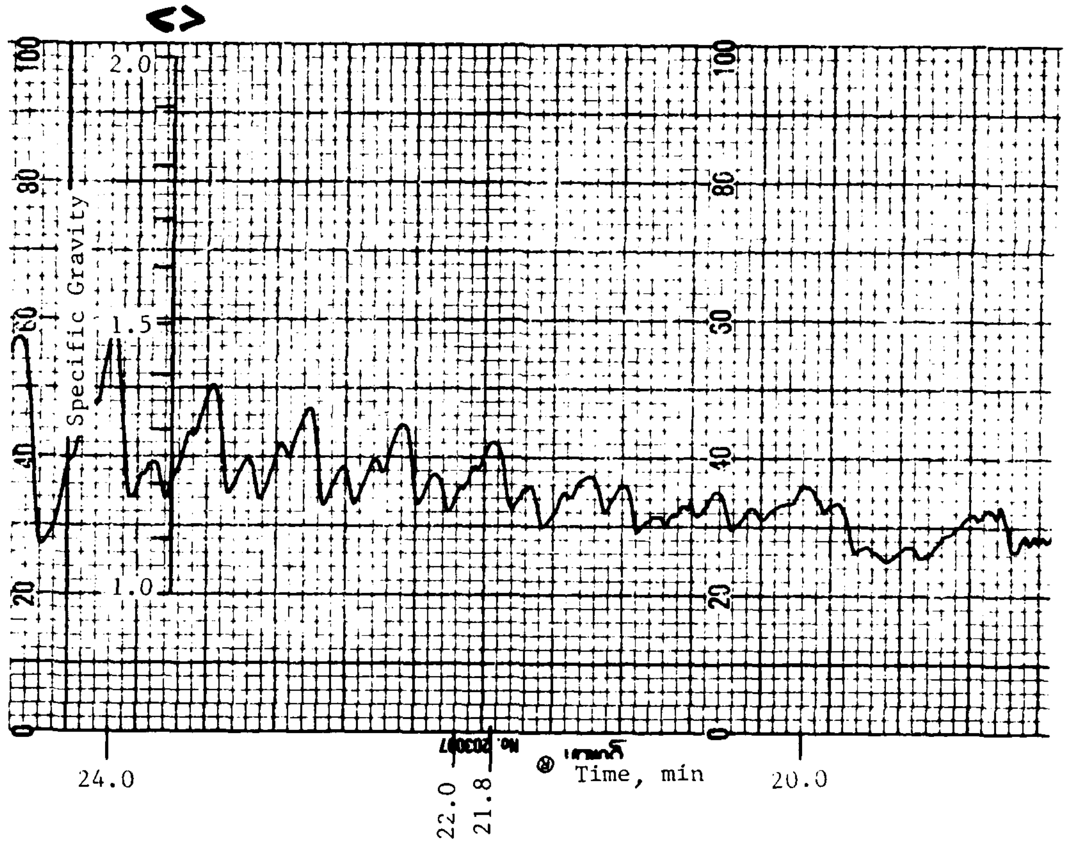


Figure 27. Discharge specific gravity, run 37, segment 1, sand tests

for a small asymmetry. The larger or longer the perturbation, the more pronounced this asymmetry would become.

50. Aside from characteristics of the PNEUMA pump, another possible cause of erratic specific gravity readings is malfunctioning of the density meter. Malfunctioning in this manner is usually characterized by unreasonable values or random output variations. Continuous records of density meter output, such as Figures 26 and 27, show neither phenomenon for the most part. On the contrary, the records give reasonable values that vary in a regular manner. Even for cases such as run 11 (Plates A10 and A12), where Appendix A plots appear almost random, there is consistent periodicity in the continuous records related directly to pump operation.

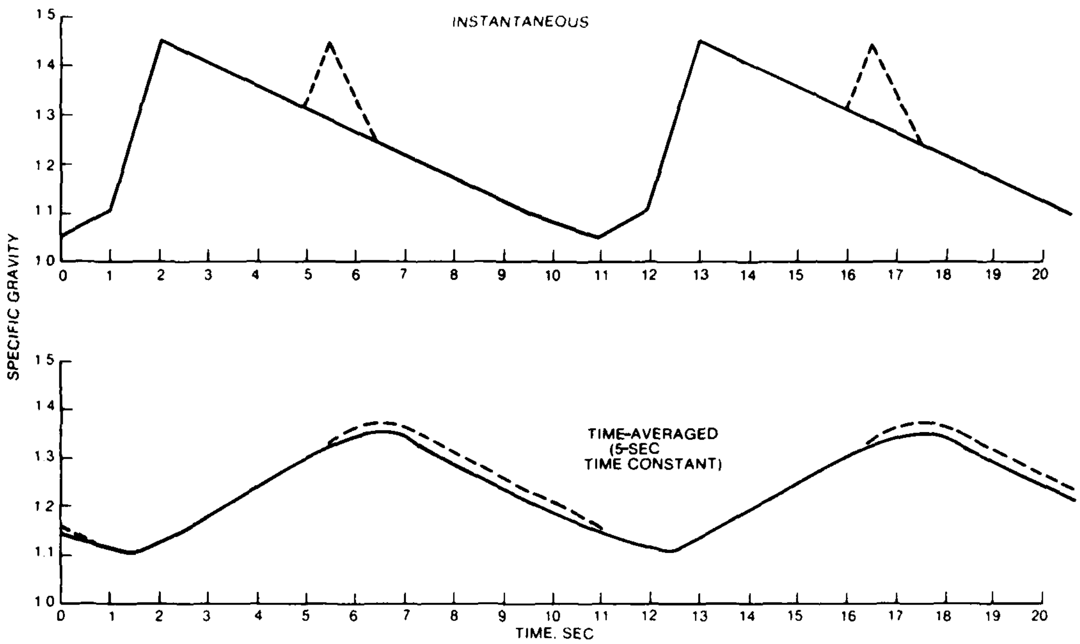


Figure 28. Hypothetical instantaneous specific gravity and time-averaged specific gravity

51. Another point evident from the Appendix A specific gravity plots is that much of the time the PNEUMA pump produced a low specific gravity discharge relative to in situ sediment specific gravity. For example, in run 11, segments 1 and 2 (Plates A10 and A12, respectively), periods of higher specific gravity last from 5 to 10 min each, surrounded by much longer intervals of essentially clear water pumping. In several runs (12-15, 30, 31, 35, and 38) specific gravity was uniformly low throughout. Specific gravities approaching in situ values were attained during testing but only briefly. For examples, see run 5, segment 2 (Plate A4); run 10, segments 1-3 (Plates A6, A8, and A9); run 33, segment 2 (Plate A26); run 36, segment 2 (Plate A35); run 37, segment 3 (Plate A41); run 39, segment 1 (Plate A46); and run 40, segment 1 (Plate A48). The highest sustained specific gravity was achieved in run 37, segment 3 (Plate A41), where it remained largely above 1.30 for 15 min, and above 1.50 for half that time. Often, the pump appeared to have difficulty in excavating sand. This could have

been due to relatively shallow water depths at both sites. It was observed that the pump could not excavate sand in water depths less than about 8 ft. Much of the testing was done in water only a few feet deeper. Since the pump as tested depends solely on ambient water pressure as an excavating force, this is a plausible explanation for poor performance. In those instances where discharge specific gravity was high, the pump sometimes had difficulty in maintaining flow. Comparison of plots of specific gravity and discharge velocity shows an inverse relationship. When specific gravity increased, discharge velocity decreased. This was especially true at Lock and Dam No. 1, where the amount of air (power) supplied to the pump was less than that at Masonboro Inlet. In some cases, such as run 10, segment 1 (Plate A6), when specific gravity approached an in situ value, discharge velocity fell almost to zero. This particular phenomenon is not evident in the Masonboro Inlet plots, although significant velocity decreases occurred (see run 37, segment 1, 32 to 36 min, in Plate A37 as an example).

52. Histograms in Appendix A of discharge percent solids summarize the best performances of the PNEUMA pump in sand. Percent solids is calculated by volume, representing the percent of the pipe cross section occupied by solid particles. The theoretical maximum percent solids is the in situ sediment solids content (67.3 percent for Lock and Dam No. 1; 61.2 percent for Masonboro Inlet). Figure 29 is a composite histogram of discharge percent solids compiled from sand test histograms in Appendix A. It is evident that the in situ solids content was never pumped at either site. For approximately 62 percent of the time covered by histograms, discharge percent solids was in the range of 10 to 25 percent. The pumping duration above 35 percent was virtually negligible (less than 5 percent).

<u>Discharge velocity</u>

53. The main information to be gathered from discharge velocity plots in Appendix A is an indication of the discharge pipeline flow regime. Three regimes are possible for sand slurry transport in a pipeline:

<u>a</u>. Flow with a stationary bed--some sand particles are moved

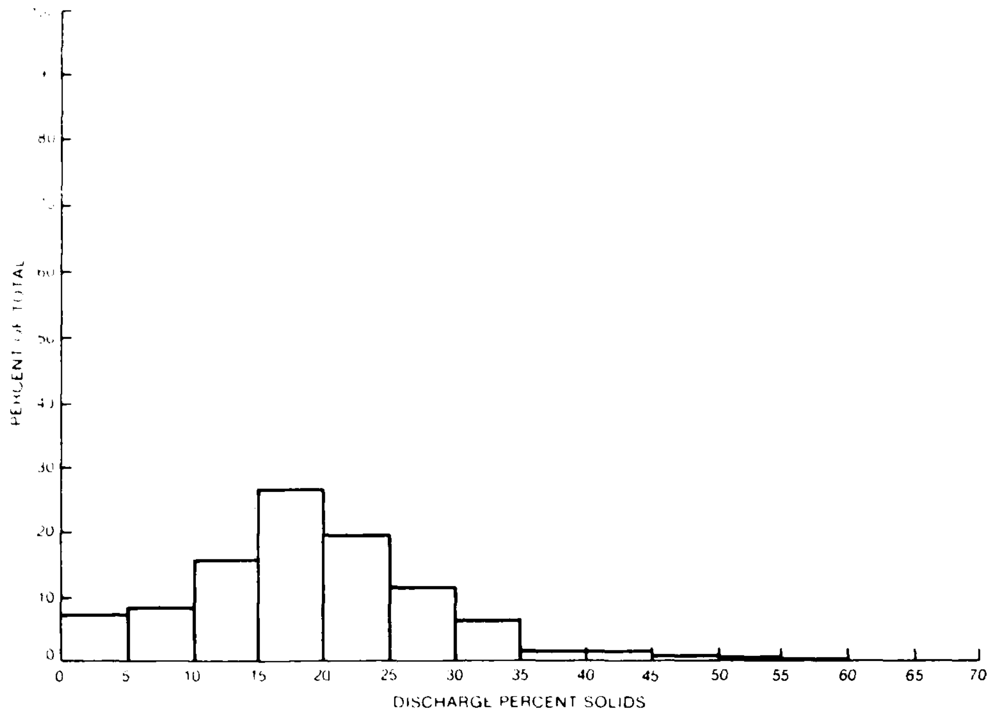


Figure 29. Composite histogram, discharge percent solids, sand tests

by the flow; others settle out to form a fixed bed on the pipe bottom.

b. Heterogeneous flow--all particles are moved by the flow, but solids concentration is greater near the pipe bottom than the top. At lower velocities in this regime, a moving bed may form on the pipe bottom.

c. Homogeneous flow--all particles are moved by the flow, and flow velocity is sufficiently high to produce uniform particle concentration over the pipe cross section.

54. Flow regime a is considered undesirable due to the possibility of the pipe being plugged by the stationary bed. Regime c does not present this problem, but is generally viewed as wasteful because of high friction losses. Regime b offers a compromise between these extremes and is usually the most desirable in which to operate. The flow velocity separating regimes a and b is called the critical velocity, V_c. The transition between b and c is marked by a velocity V_H. A number of empirical formulas are available for calculating V_c and V_H.

such as those proposed by Durand* for V_c and by Newitt et al.** for V_H. Using these relations, V_c for sand at both sites is approximately 10 fps, while V_H is roughly 23 fps for Lock and Dam No. 1 and 20 fps for Masonboro Inlet. The plots in Appendix A show that sand test flow was never in the homogeneous regime. They also show, at Lock and Dam No. 1, that discharge velocity was almost always less than V_c, in the range of 8 to 9 fps. In the first six tests at Masonboro Inlet, velocity was even less. For example, in run 33, segment 1 (Plate A24), from approximately 32 to 42 min, the discharge specific gravity was between 1.3 and 1.7 (18 to 43 percent solids) at velocities of only 4 to 5 fps through a 2000-ft discharge line. Despite these unfavorable conditions, no plugging occurred in this or any other test. In subsequent tests at Masonboro Inlet, average discharge velocity was usually equal to or greater than V_c. In a general sense, this increase can be correlated to shortening the discharge line as tests progressed. Table 3 summarizes this relationship:

Table 3

Discharge Velocities Versus Line Length

Run No.	Discharge Line Length ft	Representative Discharge Velocities fps
30-33	2000	6-8
34	2000	9-10
35-38	1520	10-11
39	740	12-13
40	420	13-14

55. Figure 30 shows portions of specific gravity and velocity continuous plots for run 11, segment 1, from 8 to 13 min. Figure 31 shows similar plots for run 11, segment 2, from 24 to 32 min. During

* R. Durand. 1953. "Basic Relationships of the Transportation of Solids in Pipes-Experimental Research," Proceedings, Minnesota International Hydraulics Convention, Minneapolis, pp 89-103.

** D. M. Newitt et al. 1955. "Hydraulic Conveying of Solids in Horizontal Pipes," Transactions of the Institute of Chemical Engineers, Vol 33, pp 93-110.

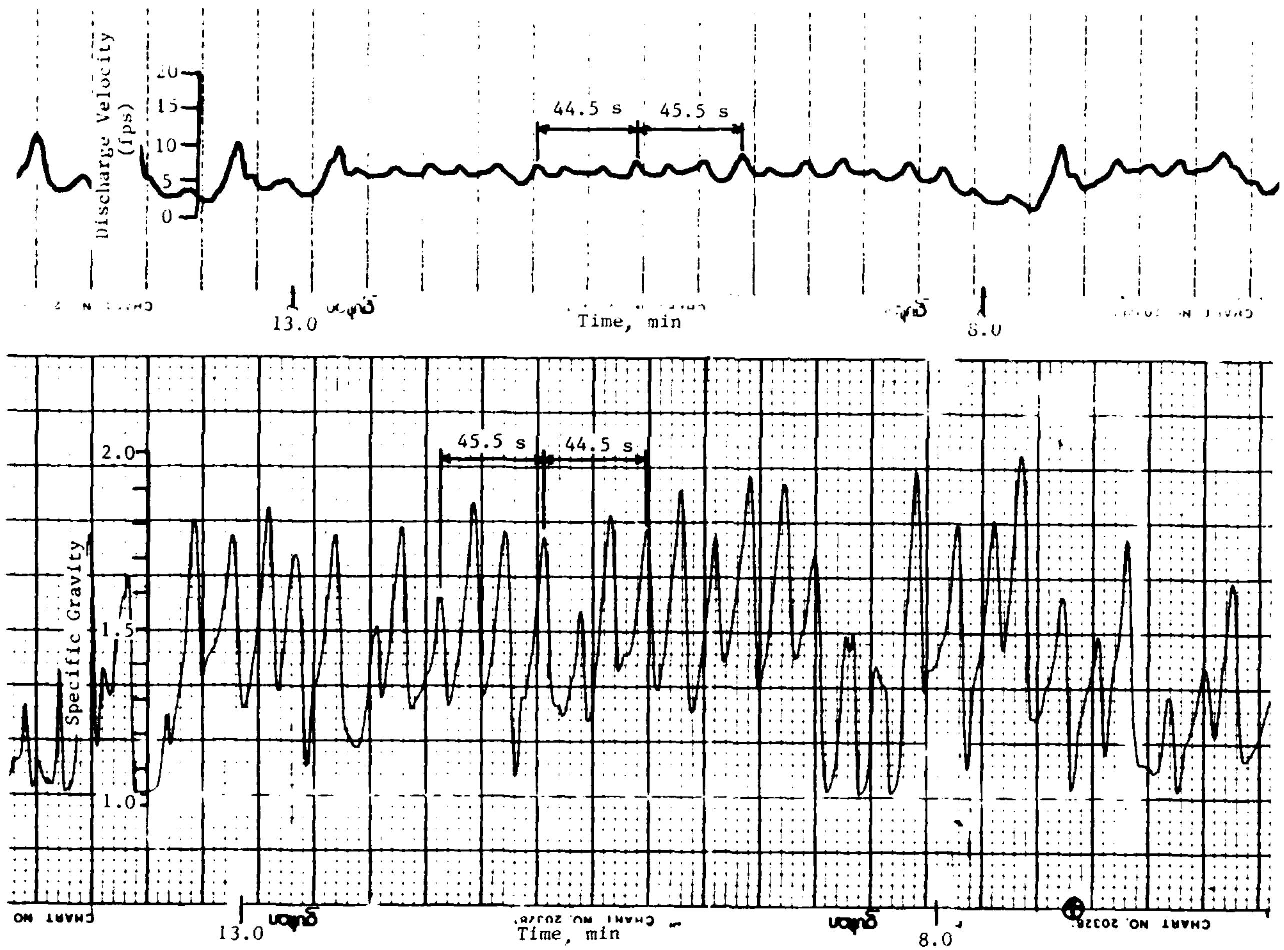


Figure 30. Discharge velocity and specific gravity, run 11, segment 1, sand tests

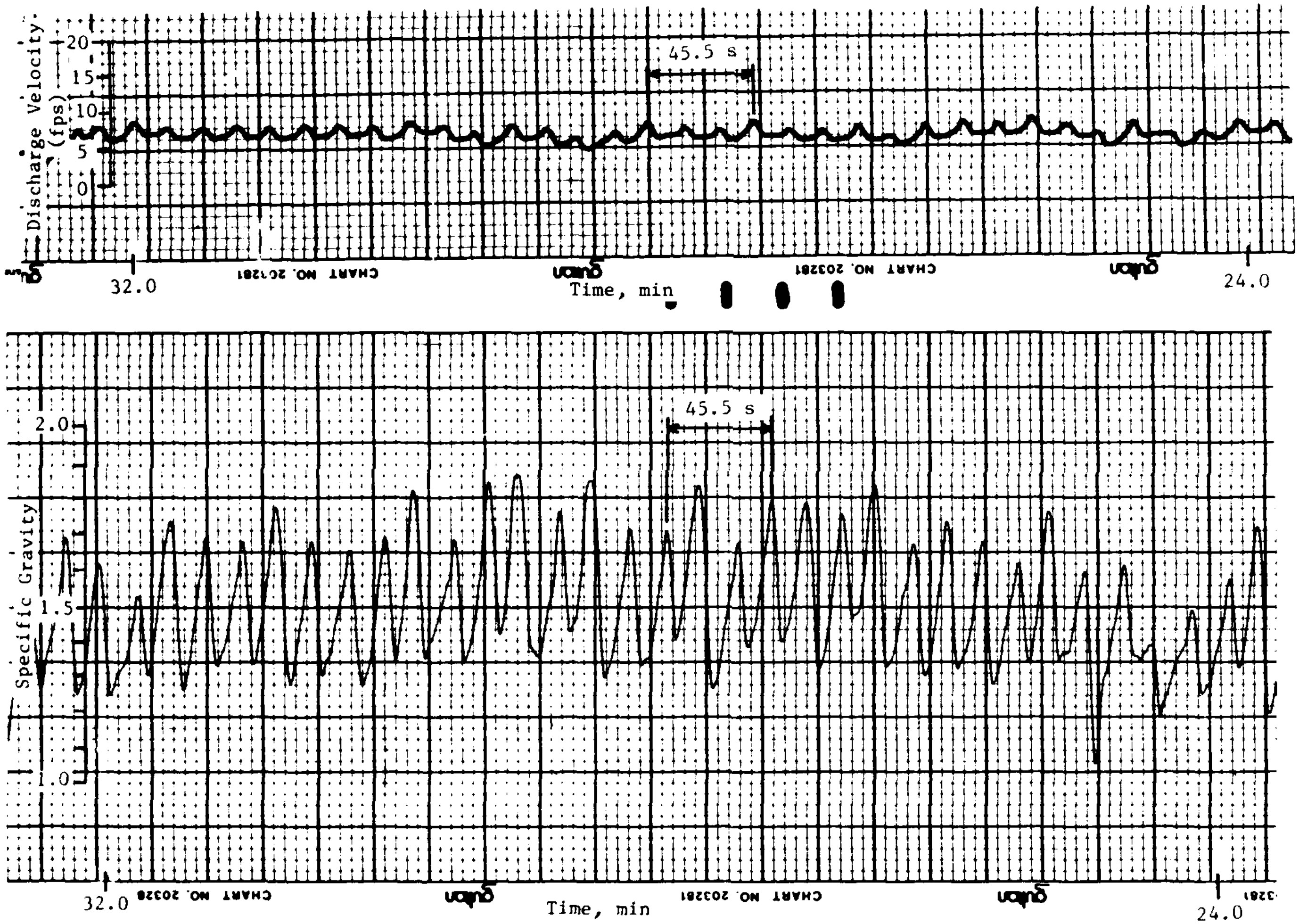


Figure 31. Discharge velocity and specific gravity, run 11, segment 2, sand tests

both time periods, the pump discharged a highly varying but reasonably dense mixture. Figures 30 and 31 show that discharge velocity varied in a manner analogous to specific gravity. The general amplitude of variation was 2 to 3.5 fps around a mean velocity of 6.7 fps. As with specific gravity, velocity variations can be related directly to pump operation. Apparently, the pump air distributor was run at a slower speed than that shown in Figure 26, since cycle time is 44.5 or 45.5 sec instead of 33.5 sec. Also, velocity and specific gravity surges within a cycle are not spaced evenly as in Figure 26. Spacing between velocity surge peaks in Figures 30 and 31 varied from 12 to 17 sec within one cycle. These variations about a mean velocity less than V_c may explain why no discharge line plugging occurred in the Masonboro Inlet tests. Instead of flow at a constant velocity less than V_c , discharge may proceed in a pulsing fashion which inhibits plug formation. However, such a mechanism is only speculation at this time.

Excavation rate

56. Figure 32 is a composite histogram of in situ excavation rates compiled from sand test excavation rate histograms in Appendix A. Excavation rates in excess of 400 cu yd/hr are virtually nonexistent (less than 4 percent total). The predominant range is 100 to 300 cu yd/hr, which totals 61 percent. Looking at the histograms for Masonboro Inlet and referring to discharge line lengths in Table 3, a general increase in excavation rate can be identified as discharge line length decreases. Excavation rates at Lock and Dam No. 1 were predominantly in the 100 to 200 cu yd/hr range, lower than those at Masonboro Inlet even though discharge line length at Lock and Dam No. 1 was much less. Several possible factors are involved in this difference:

a. Water depths at Lock and Dam No. 1, as discussed earlier, were barely enough in which to operate the pump.

b. Sand at Lock and Dam No. 1 was denser and coarser than that at Masonboro Inlet, making excavation and pumping more difficult.

c. The amount of air (power) supplied to the pump at Lock and Dam No. 1 was limited by the effects of factors a and b, among others.

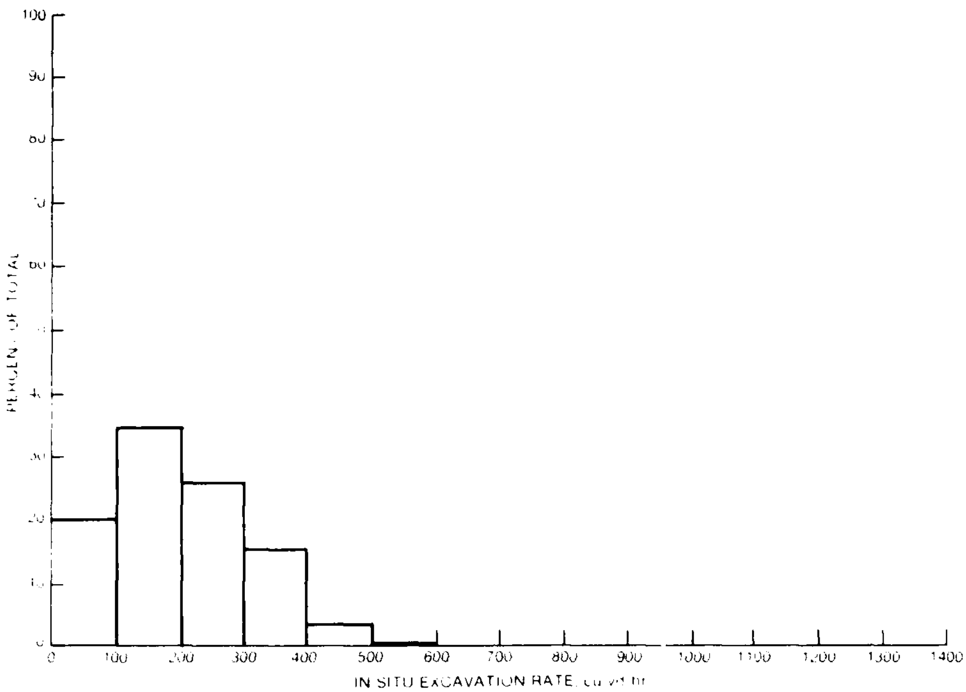


Figure 32. Composite histogram, in situ excavation rate, sand tests

Airflow rate

57. Looking at the plots of airflow versus time in Appendix A, several facts are evident. First, mean airflow rate remains generally constant for each plot, independent of discharge variations. This points out a difference in the way a PNEUMA pump draws power compared with a centrifugal or piston pump. A centrifugal or piston pump is directly coupled to the prime mover, and the amount of power drawn at a constant pump speed varies as the pump output changes. The PNEUMA pump, on the other hand, is indirectly coupled to its prime mover, an air compressor, via the air distributor. The amount of power supplied to the pump is determined by the operator, who controls the approximate volume of air to the distributor and the distributor speed. The PNEUMA pump then does what it can with this power in terms of output. As previously noted, when the pump discharge specific gravity increases, the velocity decreases in a compensating fashion. Total discharge head may also vary but not as much as velocity. In the Appendix C tables, run 33,

segment 1, from 27 to 38 min, and run 32, segment 2, from 38 back to 32 min, illustrate the nature of these variations in terms of pump parameters.

58. Although mean airflow rate remains constant, there are very obvious periodic variations during each run, especially at Masonboro Inlet. The period of these variations is mostly in the range of 120 sec, with occasional runs such as 36 and 40 in the 180-sec range. These relatively long period oscillations do not appear related to any physical phenomena, but may be a by-product of the manner in which data were sampled and recorded (see PART II, "Instrumentation," paragraphs 21 and 22). If a regular periodic function with period T is sampled at a constant interval slightly less than T, a plot based on the sample values will be a regular periodic function with a period greater than T. Figure 33 illustrates this point by showing a periodic function with an

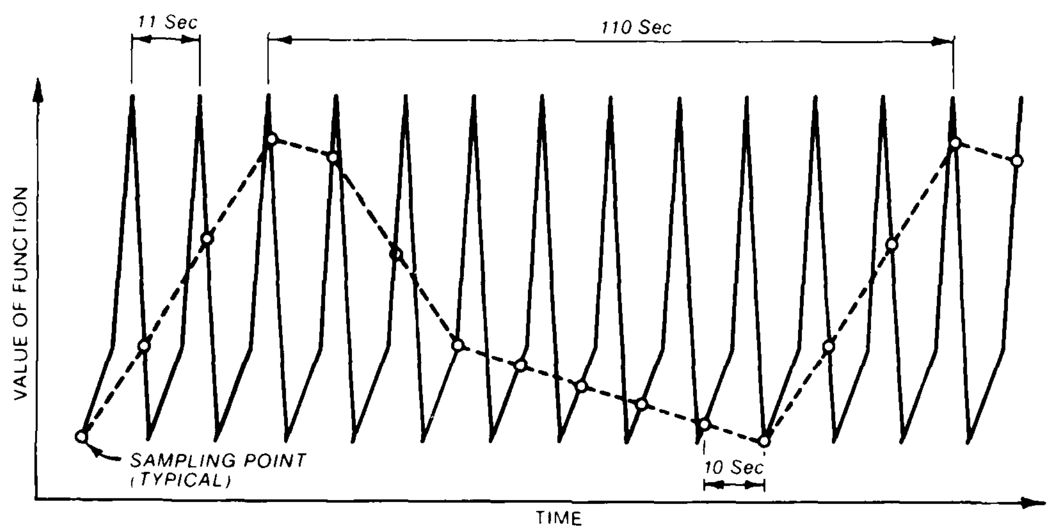


Figure 33. Hypothetical 11-sec periodic function sampled at 10-sec intervals

11-sec period sampled at 10-sec intervals. Connecting the sample values gives an apparent periodic function with a 110-sec period. No continuous records of airflow were taken during times covered by Appendix A plots. However, Figure 34 shows the continuous airflow rate just prior to segment 1 of run 6. It is obviously, a very regular periodic function

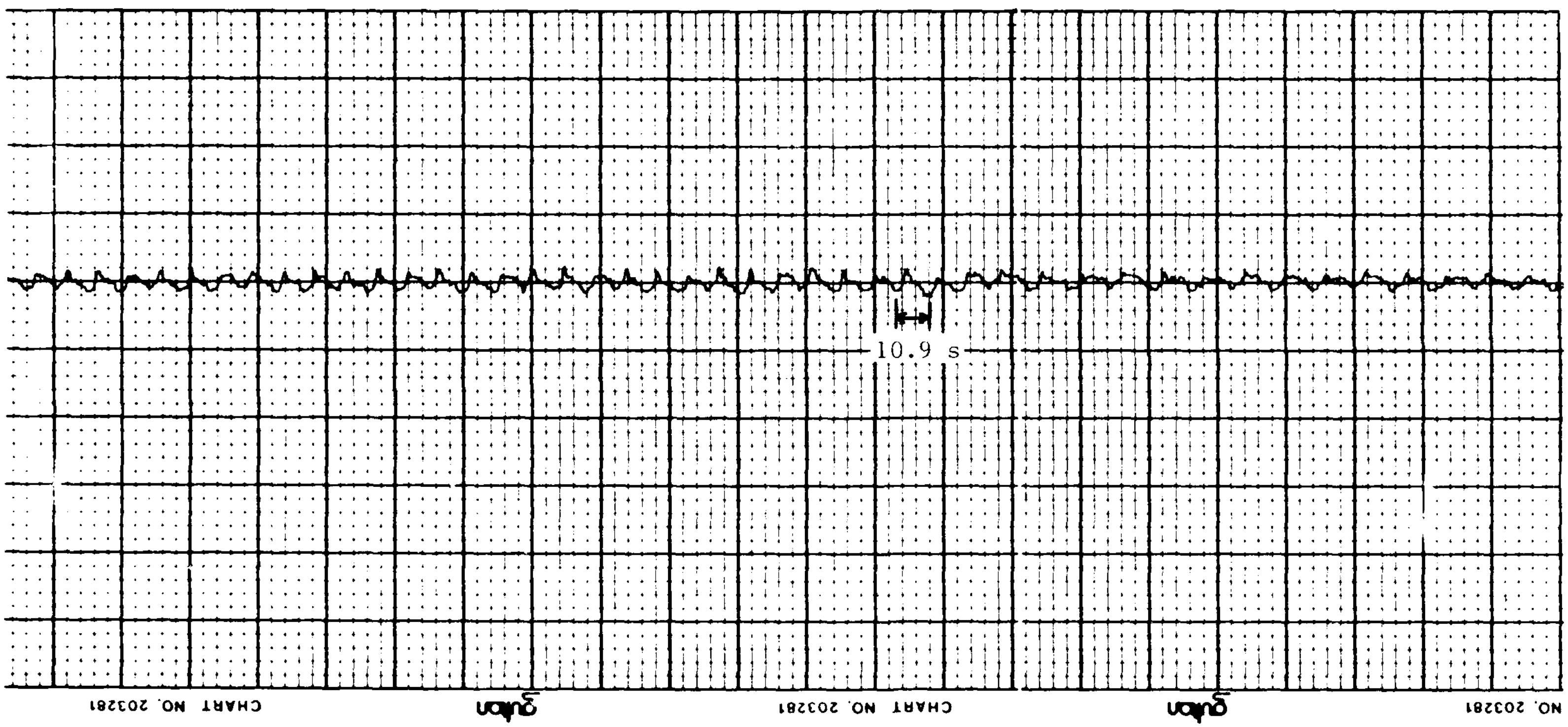


Figure 34. Airflow rate prior to segment 1 of run 6, sand tests.

with approximately a 10.9-sec period, corresponding to the air distributor speed. Sampling this function at 10-sec intervals, as done in these tests, would generate a function with an apparent period of 120 sec. This is the period of airflow rate variations shown in Appendix A plots for several runs, e.g. run 6, segment 1 (Plate A5).

Interpretation of Fine-Grained Sediment Test Data

59. Tests pumping silty clay were conducted at the MOTSU site. In addition to pumping performance, turbidity generation was also measured. Water depths at MOTSU were greater than those at the other sites and bottom material was considerably less dense. Therefore, the best pumping performance of the three sites tested should be expected. However, pump deployment at MOTSU was more difficult. For most runs, the pump had to be moved continuously along the bottom to excavate material. The method for doing this (dragging the pump behind the *Snell*) was makeshift at best. The effect of this deployment method may have been to counteract some site advantages.

Discharge specific gravity

60. Comparison of plots in Appendix A of discharge specific gravity shows that fine-grained sediment tests appear similar in form to sand tests. Plots are similarly variable, although variation amplitude is less than that for sand tests. At times, when discharging a high specific gravity mixture at MOTSU, density meter output was almost steady. Figures 35-37, which are portions of continuous discharge density records for different runs, illustrate this point and show that the cyclic density variation noted in sand tests and related to several aspects of pump operation virtually disappeared at higher densities. Figure 37 shows some variation, especially between 11 and 14 min. Figure 38, which illustrates a run when steady output was never achieved, shows a similar pattern. However, in both figures, the variation is continuous over one pumpout cycle of all three pressure vessels, with no evidence of individual vessel contributions as shown in Figures 26 and 27 for sand tests. Variations shown in Figures 37 and 38 may be due in part

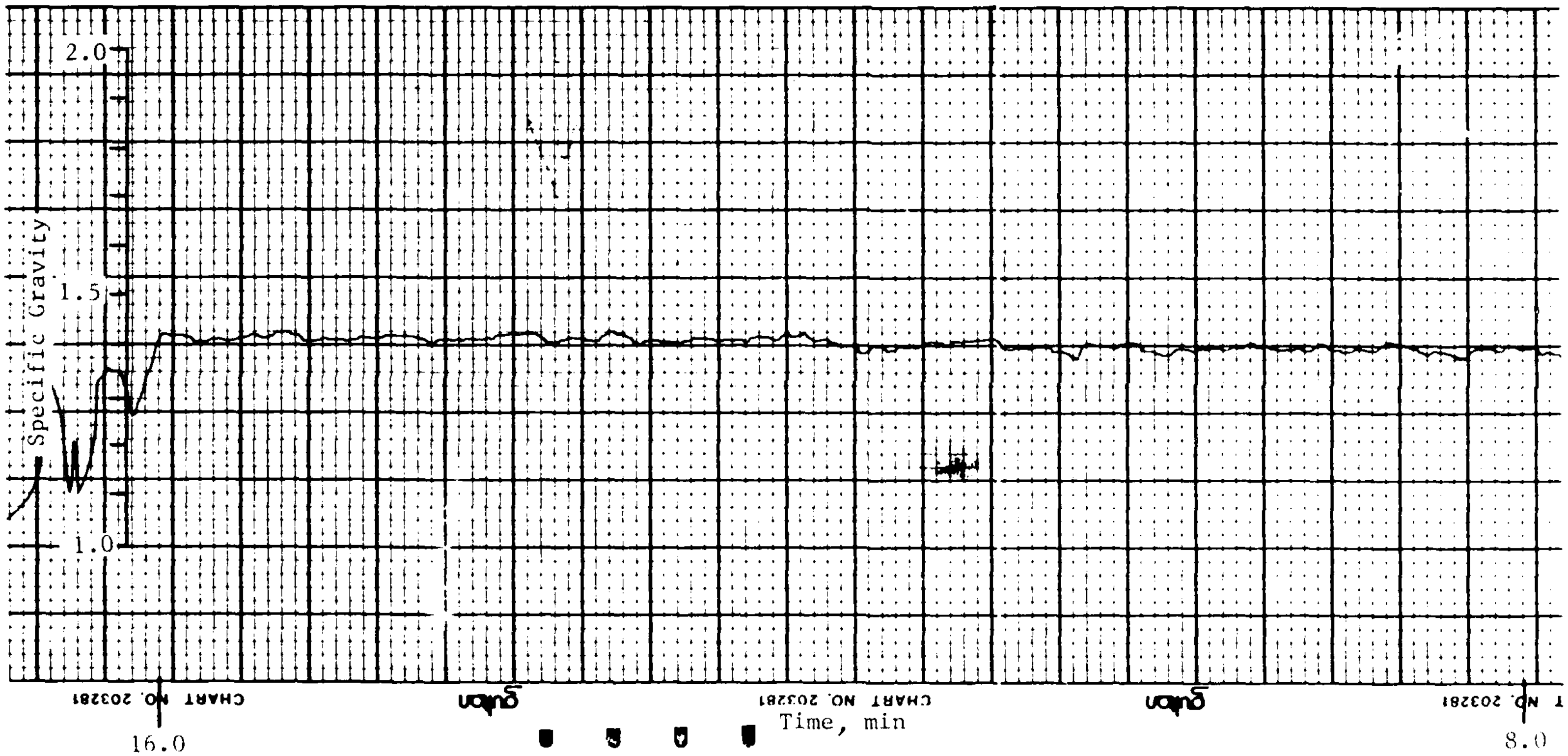


Figure 35. Discharge specific gravity, run 20, segment 2, fine-grained sediment tests

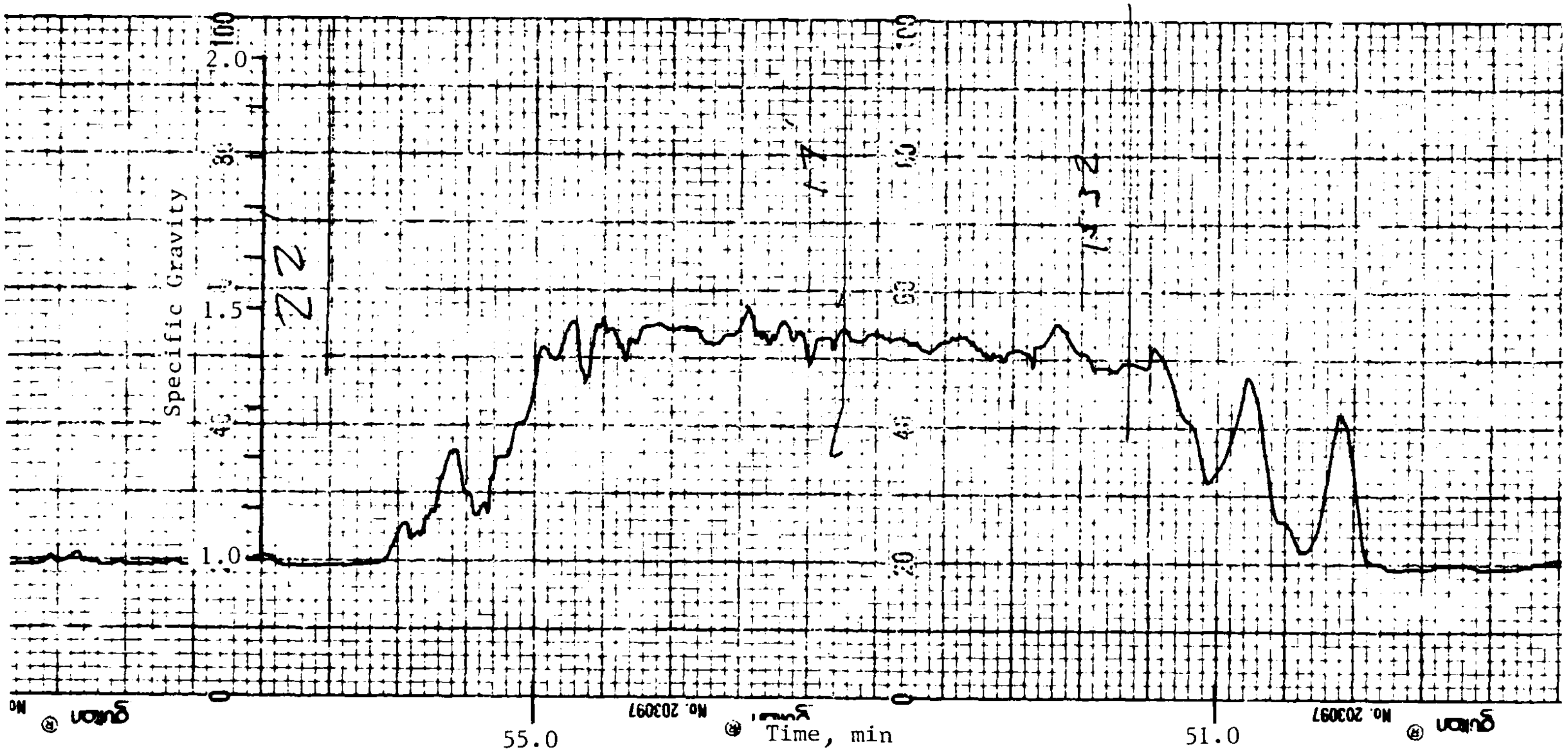


Figure 36. Discharge specific gravity, run 44, segment 2, fine-grained sediment tests

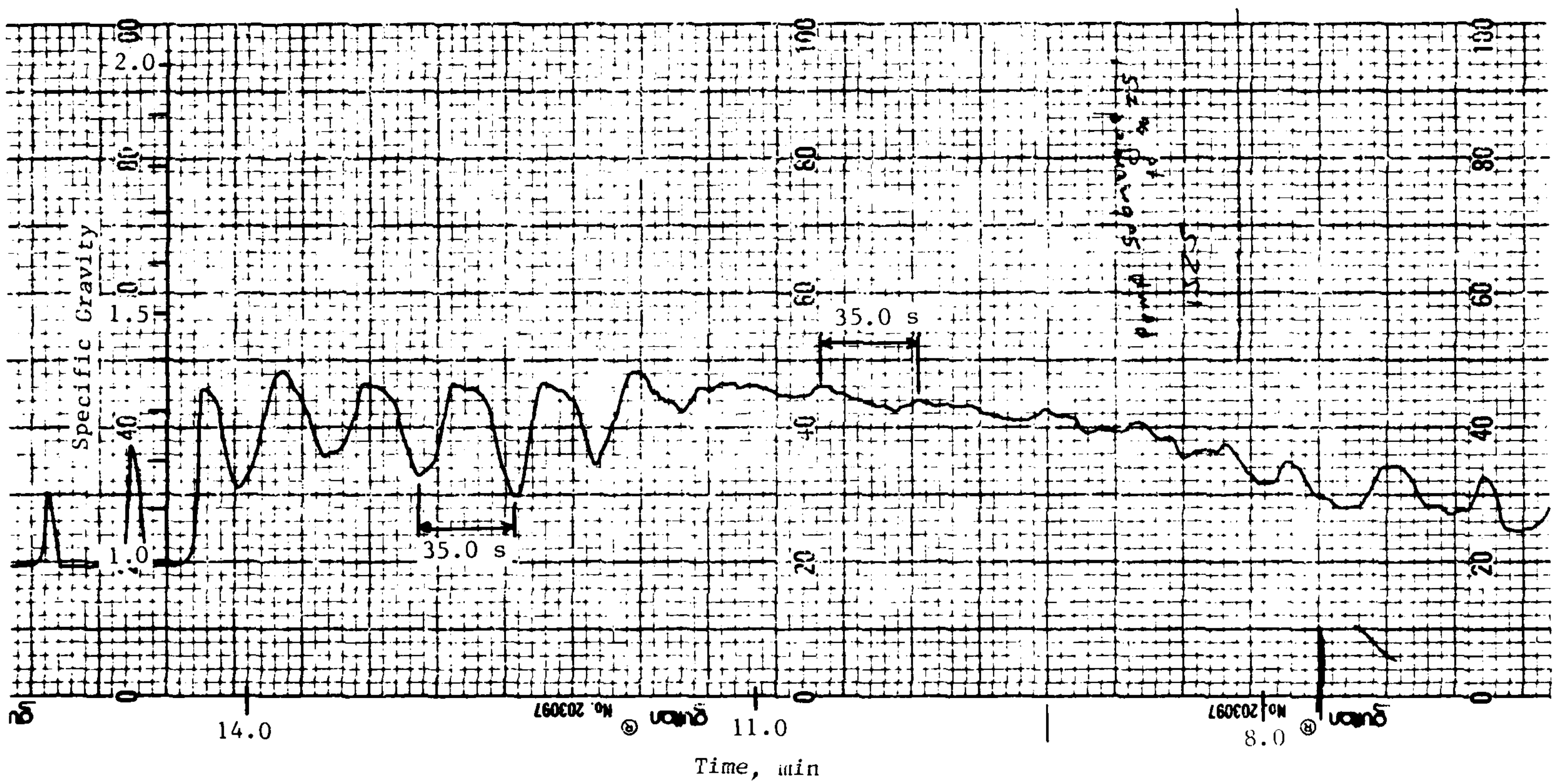


Figure 37. Discharge specific gravity, run 44, segment 1, fine-grained sediment tests

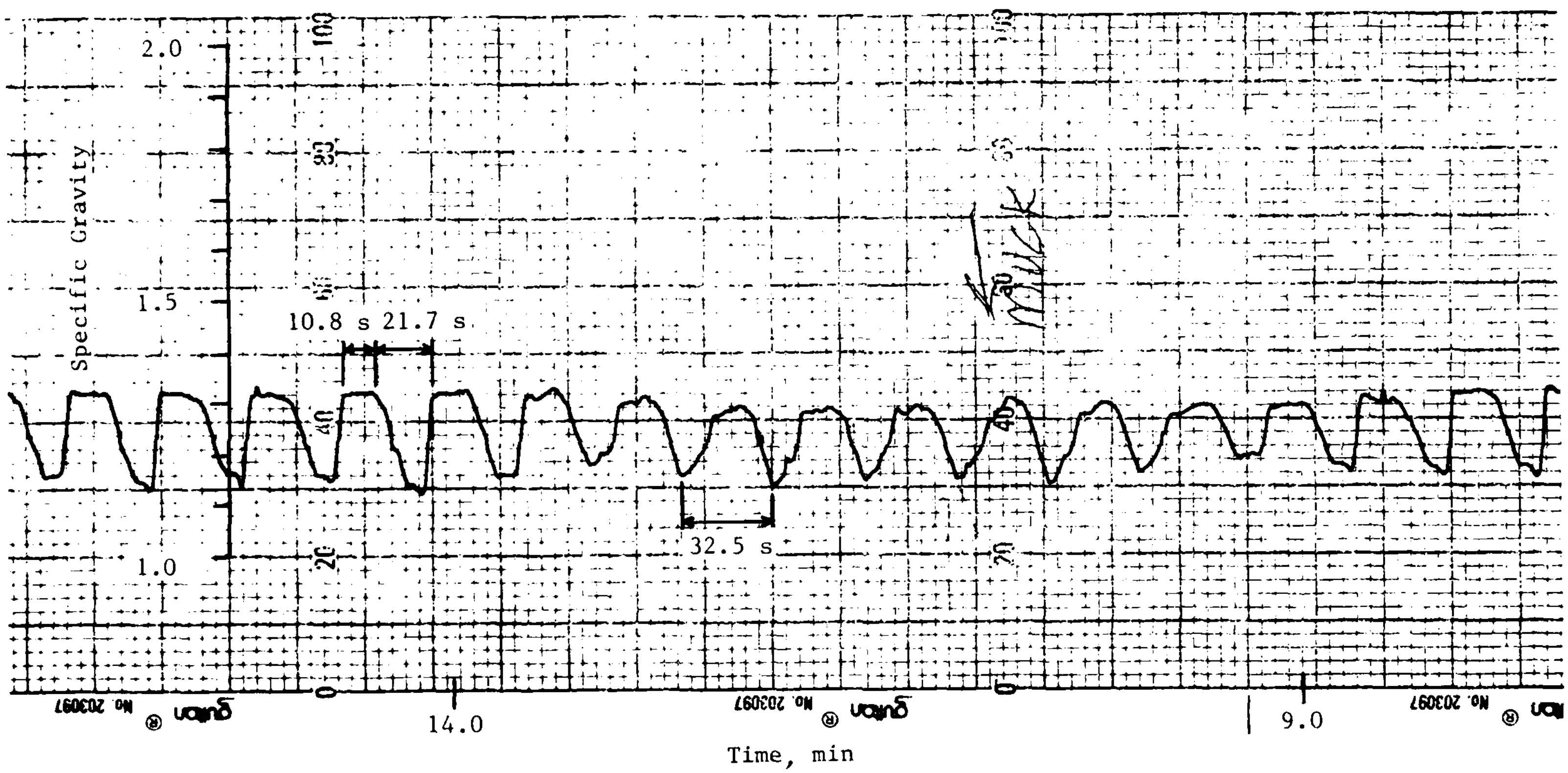


Figure 38. Discharge specific gravity, run 27, segment 2, fine-grained sediment tests

to the suction attachment used in most tests at MOTSU and the mode of pump operation. Figure 39 shows suction attachments used in the sand

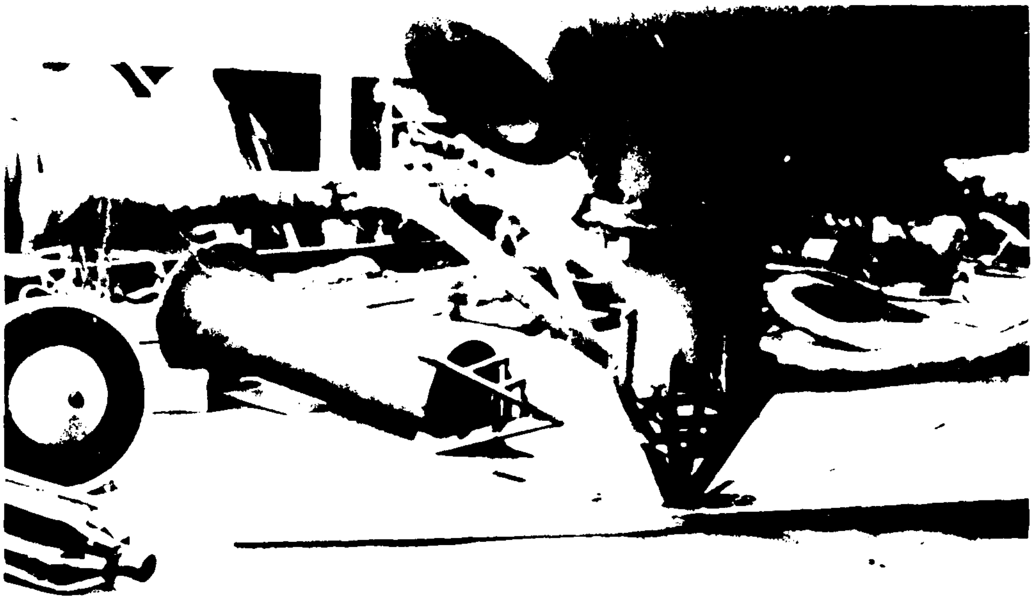


Figure 39. Straight pipe suction attachments

tests and runs 16-20 at MOTSU. These were short sections of straight pipe with open points on the bottom. Each pressure vessel had an identical attachment. By lowering the pump vertically to a smooth, uniform bottom, a theoretically identical excavating environment could be created at each suction. Although this never resulted in steady discharge densities in the sand tests (see paragraphs 46-49), it did in run 20 at MOTSU. Attachments used at MOTSU subsequent to run 20 were horizontal shovel-like intakes, all facing in the same direction (Figure 40). When pulling the pump along even a smooth bottom, two of these intakes would be parallel while the third trailed between them. The result of this configuration may have been partial starvation of the trailing intake, causing a periodic drop in discharge specific gravity; or the pump may have been oriented partly sideways, so that one intake was leading and the others were trailing. Support for the latter explanation is given by the fact that "plateaus" of steady high specific gravity in each cycle last approximately one-third of the cycle, while

Figure 40. Shovel-like suction attachments

"valleys" in between span the remaining two-thirds (see Figure 38 at 14 min). In any event, the PNEUMA pump was more capable of a steady high density discharge at MOTSU than at the sand test sites. This result should be expected, since material at MOTSU was less dense, easier to excavate, and not as prone to settling in the pressure vessels as sand. Also, greater water depths at MOTSU undoubtedly aided excavation.

61. Although a steady high density discharge could be achieved at MOTSU, sustaining it for long periods of time was difficult. The longest period of steady high density pumping was an 11-min interval in run 20, segment 2 (Plate A60), when discharge specific gravity was a constant 1.40. The pump was fitted with straight pipe attachments, shown in Figure 39, and was operated in one spot during this interval. Apparently, the pump was buried far enough in the somewhat fluid sediment that it could obtain a constant feed of mud at in situ density. In later tests with shovel-like suction attachments and a moving pump, constant suction feed was more difficult to achieve, and average

densities were less. For example, in run 27, segment 2 (Plate A76), a periodically varying discharge density averaging slightly over 1.20 specific gravity was sustained for 16 min.

62. Figure 41 is a composite histogram of discharge percent

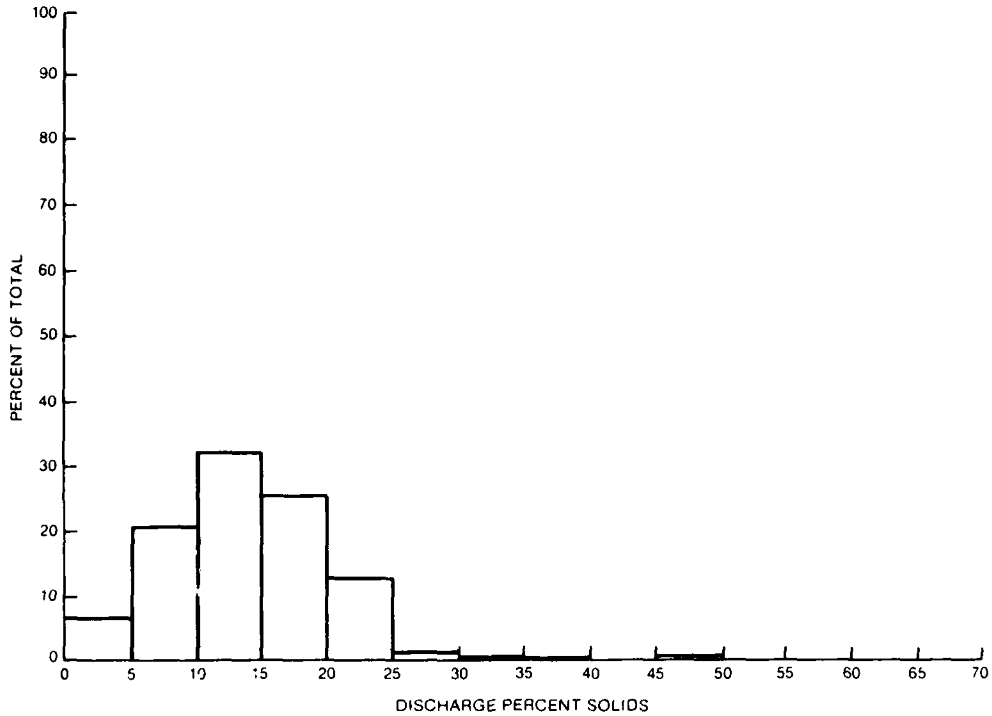


Figure 41. Composite histogram, discharge percent solids, fine-grained sediment tests

solids for the best pump performances at MOTSU. As discussed earlier, sediment at MOTSU was assumed to have a 1.23 specific gravity, corresponding to in situ solids of 14 percent. Figure 41 shows that this value was exceeded approximately 46 percent of the time during periods of good performance; 92 percent of the time, discharge percent solids was between 5 and 25 percent. These solids percentages correspond to specific gravities of 1.08 and 1.41, respectively. Referring to Figure 22, the range of specific gravities in MOTSU core samples was 1.094 to 1.532. It appears, therefore, that the PNEUMA system at MOTSU was capable of excavating and pumping material at an almost in situ density, given adequate deployment conditions. This is in direct contrast to

the sand tests, where in situ density was never achieved.

Discharge velocity

63. The concept of flow regimes in the discharge pipeline, as discussed in paragraph 53, has little application to sediment pumped at MOTSU. The sediment median grain size is approximately 0.008 mm in the test area (Soil and Material Engineers, Inc.*). Based on Stokes' law, the settling velocity of a spherical quartz particle of this diameter would be approximately 0.001 fps, classifying the in situ sediment as a "nonsettling" mixture in terms of pipeline flow. This means that the mixture probably flows in a homogeneous fashion regardless of velocity. The inverse relation of discharge velocity to specific gravity noted in the sand tests held true at MOTSU (see Plates A52, A58, A60, A64, and others). Discharge velocities were mostly in the range of 8 to 13 fps.

Excavation rate

64. Excavation rates for the MOTSU tests, as discussed earlier, are expressed in terms of the equivalent rate for an assumed sediment density. The actual in situ volume excavated may be more or less, depending on the ratio of in situ sediment density to assumed density. This fact should be kept in mind when looking at Figure 42, which is a composite histogram of excavation rates. In comparison to the same histogram for sand tests (Figure 32), excavation rates for MOTSU are much greater in value and range. Rates are almost evenly distributed between 300 and 900 cu yd/hr, a range which contains 77 percent of the total distribution. Excavation rates for MOTSU sediment can also be expressed in terms of equivalent sand rate by multiplying by the ratio of assumed MOTSU sediment density to sand density (approximately 0.6). Figure 43 shows a histogram derived from applying this ratio to the histogram of Figure 42. Comparing this histogram to that for the sand tests (dotted line), it appears the PNEUMA pump was capable of greater equivalent excavation rates at MOTSU. The median excavation rate for sand tests was approximately 185 cu yd/hr, while the median equivalent

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* Op. cit., page 25.

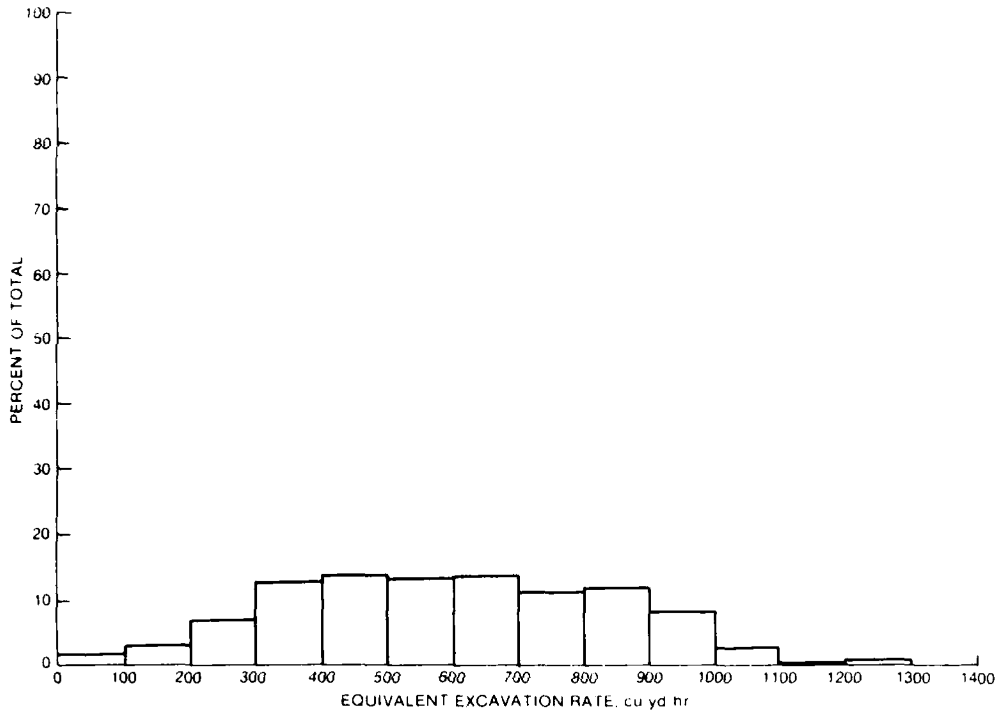


Figure 42. Composite histogram, excavation rate, fine-grained sediment tests

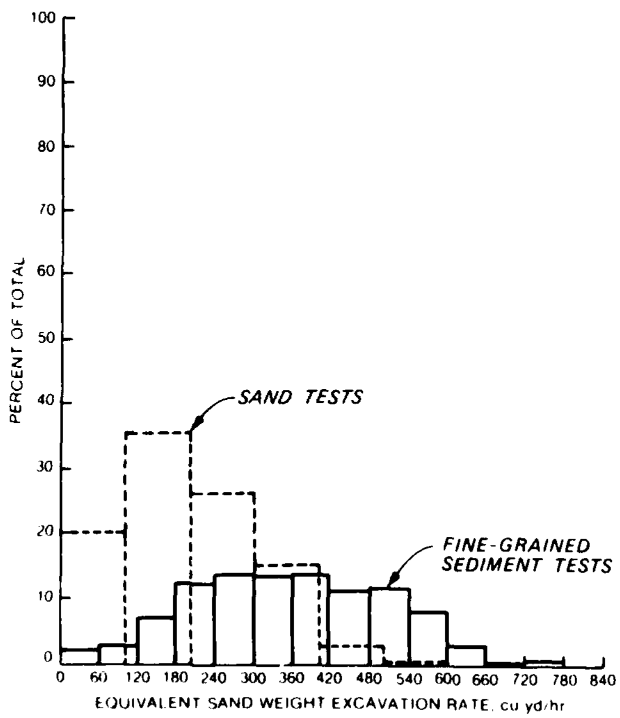


Figure 43. Composite histogram, equivalent sand weight excavation rate

sand rate for MOTSU was 350 cu yd/hr, almost twice as great. The difference between these figures is not unexpected, since MOTSU sediment was less resistant to excavation and water depths there were greater. The difference magnitude indicates that the PNEUMA pump's performance may be greatly affected by factors such as soil excavation resistance and changes in water depth when operating in situations typical of many maintenance dredging projects.

Airflow rate

65. Airflow rates at MOTSU were, in general, higher than those for Lock and Dam No. 1 and lower than those for Masonboro Inlet. This might be expected, since water depths were less at Lock and Dam No. 1 and the increase of airflow with increasing depth was established in clear water tests (Figure 23). At Masonboro Inlet, although depths were less than those at MOTSU, pump discharge heads were higher. This was due to the longer discharge pipeline and coarser material pumped at Masonboro. For example, in Appendix C, compare airflow rates for run 44, segment 2, 27 to 31 min (MOTSU), with run 34, segment 1, 35 to 40 min (Masonboro). Specific gravity and flow rate are approximately the same for each, yet the averaged airflow rate for Masonboro was 400 scfm greater. In this particular instance, the water depth for each run was about the same (18 ft for run 34, segment 1; 20 ft for run 44, segment 2). The only real difference, therefore, was pump discharge head. The averaged discharge head for the MOTSU example was 42.4 ft versus 79.3 ft for Masonboro.

66. The cyclic fluctuations in airflow rate noted in sand tests are present in the MOTSU Appendix A plots. The fluctuation period is approximately the same but the amplitude is generally less in MOTSU plots than for Masonboro Inlet. Compare, for instance, run 44, segment 2, 27 to 40 min (Plate A92, MOTSU), with run 38, segment 3, 22 to 30 min (Plate A45, Masonboro Inlet). Average discharge velocity and specific gravity were approximately equal in each case, as was the period of airflow fluctuation. However, fluctuation amplitude in the MOTSU test was about 100 scfm versus 230 scfm for the Masonboro test. Reasons for this difference are difficult to determine. It may be that higher airflow

rates used at Masonboro caused instability in the air supply system independent of the PNEUMA pump; or the more stable discharge specific gravity at MOTSU may have caused less fluctuation in air demand per air distributor cycle. Support for both hypotheses can be found when comparing Appendix A airflow plots.

Water depth effects

67. No correlation of substance could be found linking pump performance to water depth at MOTSU. Although the water depth range was fairly broad (12 to 35 ft), 21 of the 29 tests were run in the narrow depth range of 25 to 30 ft. Of the remaining 8 tests, 2 were at a 12-ft depth, 1 at 20 ft, 1 at 33 ft, and 2 at 35 ft. Considering the variety of other variables which affected pump performance at MOTSU, a substantial number of tests were needed at each depth to establish depth-related trends. Operational and time limitations made such data collection impractical.

Turbidity Generation Tests

68. Equipment used for measuring turbidity generated by the PNEUMA pump at MOTSU was described in paragraph 24. Two pumped sample collectors were employed, each sampling simultaneously from depths of 0, 5, 10, and 15 ft. One collector was located immediately adjacent to the PNEUMA pump; the other was deployed from a small boat downstream of the pump at varying distances. In this manner, it was hoped to measured turbidity generated at the pump and the extent of any turbidity plume.

69. Turbidity was monitored for three test runs at MOTSU, Nos. 21, 22, and 23. Water samples were taken for the duration of each run at 10-min intervals. The first set of samples for each run was taken prior to pumping to establish naturally occurring (background) turbidity. Appendix B contains tables giving turbidity and suspended solids analysis for each sample. During run 21, the first three sets of downstream samples were taken 25 ft behind the *Snell*. Remaining downstream samples for this run were taken 100 ft behind the *Snell*. Two of these were taken in the turbidity plume generated as the Snell and the Currituck

moved in a circle centered approximately 200 ft from Wharf No. 3. For run 22, downstream samples were taken 25 to 200 ft behind the *Snell*. Two downstream samples were taken in undisturbed water for background, and one was taken downstream of the *Currituck* with a full load of dredged material. Run 23 was conducted in a manner similar to run 22, except that only one downstream sample was taken for background data. For runs 22 and 23, dredging was done parallel to Wharf No. 3 in a relatively straight line. Results of analyzing the turbidity data are summarized in the following paragraphs:

a. Run 21. . might be expected, the highest suspended solids concentrations were found in samples taken at lower depths. The highest values taken downstream from the pump were found in sample set 21-50 in the turbidity plume. However, set 21-80 taken 30 min later in the same turbidity plume showed a significant decrease in suspended solids and turbidity. This seems to indicate that any turbidity generated was relatively small and intermittent, since no suspended material buildup was apparent. This hypothesis is supported by the fact that samples taken adjacent to the pump show little variation from background values. No trend is evident with regard to dredging duration.

b. Run 22. The only relatively high turbidity and suspended solids values downstream of the *Snell* are in sample set 22-55, in the *Currituck* plume and to a lesser extent set 22-60. All other downstream samples are in the background range values. Again, no duration trend can be seen, and higher values are generally near the bottom. Samples taken adjacent to the pump are also in the background range, except for a few near the bottom (22-A30-15 in particular). These isolated high values may have been caused by the sampling pump contacting the bottom.

c. Run 23. Results are essentially the same as runs 21 and 22. No duration trend is seen. Highest downstream values were in the *Currituck* wake (set 23-40). All other samples were mostly of background level.

70. Results of this turbidity monitoring program should not be considered definitive. Appendix A plots of pumping performance for runs 21 through 23 show that most of the time the PNEUMA pump was discharging water or extremely dilute sediment. Periods of high density sediment discharge were generally short, the longest being a 15-min interval at the end of run 22, segment 1. This fact could in itself

explain why no buildup of turbidity over time was noted. However, looking at the rest of the MOTSU tests, only a few had longer periods of high density sediment discharge. The monitored runs appear representative of conditions encountered at MOTSU; therefore, it is not likely that more monitoring would have identified a turbidity buildup. The problem seemed to lie in the inability of the PNEUMA pump as deployed to maintain a reasonable discharge density for any length of time. On the other hand, none of the samples taken adjacent to the PNEUMA pump showed significant increase in either turbidity or suspended solids. Such an increase might be expected even if the pump were generating only intermittent turbidity. Therefore, although the turbidity tests do not support conclusively the manufacturer's claim of little or no turbidity generation, the results appear to lean in that direction. A situation identified by this monitoring was that discharging into the Currituck created a small but measurable turbidity plume.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

71. The following general conclusions can be made from tests described in this report:

a. The PNEUMA pump was able to dredge at almost in situ density in a loosely compacted, silty clay typical of many estuarine sediments.

b. The PNEUMA pump was not able to dredge sand at in situ density. The best that could be achieved was approximately one-half in situ density.

c. Discharge densities of any significance could not be sustained longer than 15 min in either silty clay or sand. In the silty clay tests, this appeared to result primarily from pump deployment methods used. In the sand tests, a number of other factors may have contributed in addition, such as shallow water depths and resistance of the sand to excavation.

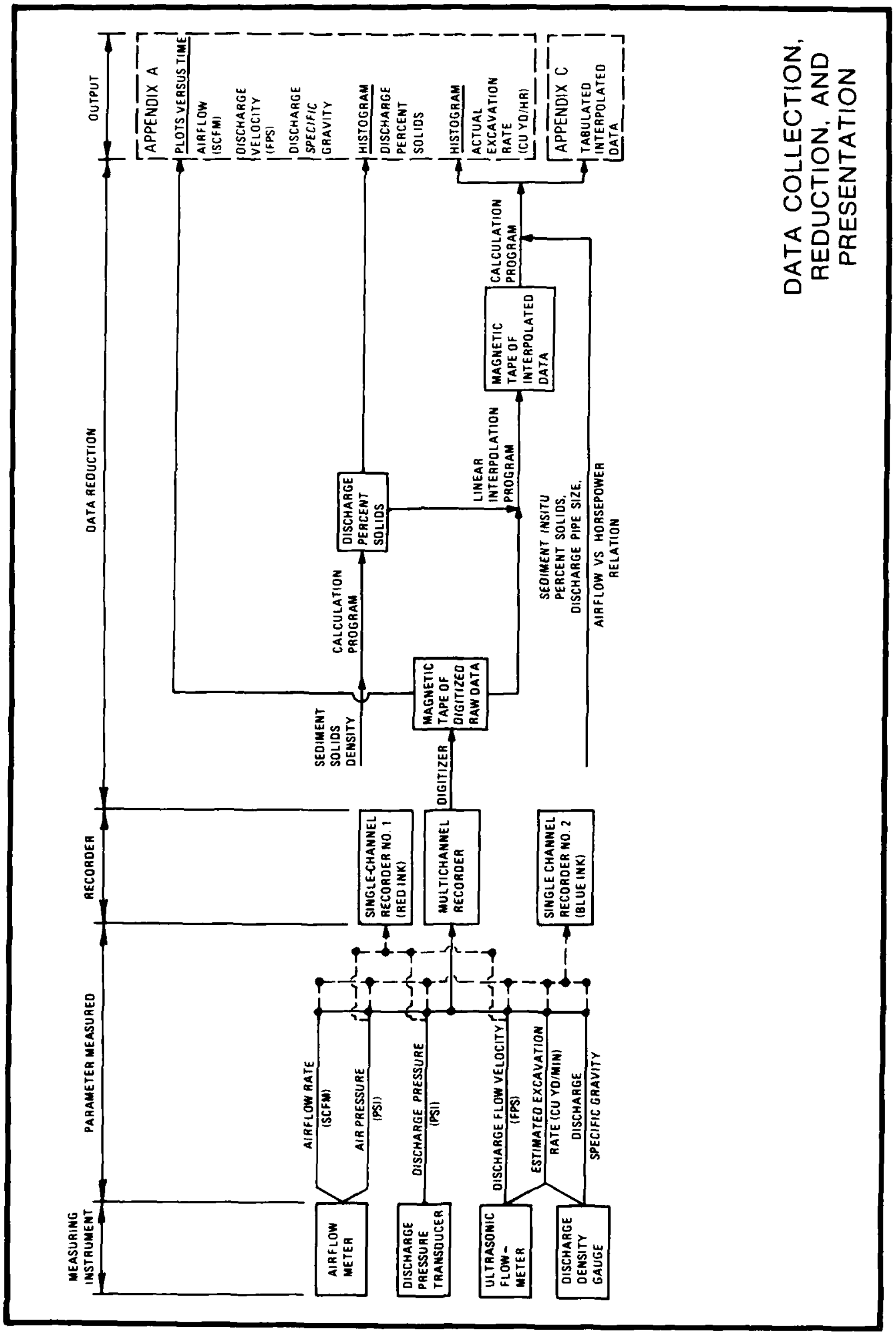
d. As a pure pumping device, the PNEUMA pump has a very low power efficiency compared with a conventional centrifugal pump. Efficiencies pumping water, sand, or silty clay were always less than 20 percent and often less than 10 percent.

e. Results of turbidity monitoring, although not definitive, seemed to support the manufacturer's claim that the PNEUMA pump generates a low level of turbidity in loosely consolidated, fine-grained sediments.

72. From the standpoint of Corps of Engineers' maintenance dredging requirements, the testing program employed had some good and some weak points. The good points were that the range of water depths and sediment types encountered were representative of many maintenance dredging situations. The weakest point, and a very important one in terms of test results, was that the deployment methods used were not conducive to good pump performance. There is little question that the PNEUMA pump could have produced more in terms of sustained excavation rates, if not discharge density, with better deployment. However, because of its weight and bulk, the model tested would have been difficult to deploy properly using anything but specialized equipment.

73. In summary, results of these tests substantiate at least partially claims of the PNEUMA pump manufacturer regarding high density

slurry pumping and low turbidity generation. Since these tests were performed, a newer model of the PNEUMA pump has become available in the United States. This model incorporates features such as a pressure vessel evacuating system to improve shallow-water performance, an electronic pump control that eliminates the mechanical air distributor, a suction agitator to improve the pump's excavating ability, and considerable reductions in weight and bulk. Many of these features seem aimed at improving performance in areas identified in this report as weak points of the Model 600/100. Therefore, it is recommended that this newer model be investigated, preferably in a laboratory situation, to determine whether in fact improvements have been made. If they have, it is believed that the PNEUMA pump may provide a capability which does not exist at present in Corps dredging work, either in-house or by contract: the ability to excavate and pump sediments at in situ densities, without creating significant turbidity at the dredging site, in water depths commonly found in maintenance dredging work, and without specialized deployment equipment.



DATA COLLECTION, REDUCTION, AND PRESENTATION

PLATE 1

APPENDIX A: EQUATIONS, DEPTH EFFECTS, AND DATA PLOTS

Equations

1. The following equations were used in the data reduction process schematized in Plate 1, main text:

for sand tests

$$CV = 100 \left(\frac{SGDIS - 1}{1.65}\right) \tag{A1}$$

for fine-grained material tests

$$CV = 100 \left(\frac{SGDIS - 1}{1.70}\right) \tag{A2}$$

$$EXC = \frac{CV1 \times VDIS1 \times 73.067}{SOL} \tag{A3}$$

$$WHP = (VDIS1 \times SGDIS1 \times 0.06217) \left[\left(\frac{PDIS1 \times 2.307}{SGDIS1}\right) + \frac{VDIS1^2}{64.4}\right] \tag{A4}$$

$$BHP = SCFM1 \times 0.23 \tag{A5}$$

$$EFF = \frac{WHP}{BHP} \tag{A6}$$

$$QDIS = VDIS1 \times 245.92 \tag{A7}$$

$$HDIS = (PDIS1 \times 2.307) + \frac{VDIS1^2}{64.4} \tag{A8}$$

2. The symbols used in Equations A1 through A8 are defined as follows:

Measured data -

SGDIS - discharge specific gravity

SCFM - airflow rate, scfm
VDIS - discharge velocity, fps
PDIS - discharge pressure, psi
CV - discharge percent solids
SOL - sediment in situ percent solids

Interpolated data -

Same as symbols for measured data, but with numeral "1" added (example: CV1).

Calculated quantities -

EXC - excavation rate, cu yd/hr
WHP - output horsepower
BHP - input horsepower
EFF - efficiency
QDIS - discharge flow, gpm
HDIS - total discharge head, feet of water

Depth Effects

3. In Figure 23 in the main text, airflow rate supplied to the PNEUMA pump is presented as a linear function of depth. Assuming that suction and discharge conditions, air distributor speed, and position of the air bypass valve remained the same, it can be shown from a simple gas law that this linear relation is a reasonable approximation. Figure A1 shows a single PNEUMA pressure vessel in the instant before air is forced in to discharge its contents. The vessel contains a certain volume of material being pumped (assume water) and the discharge line is also full of this material from previous pumpouts. Assume that the vessel discharges at a constant elevation above the water surface. Soon after discharge begins, an equilibrium will be reached between supply air pressure, P_A, and pressure in the discharge line, P_D. Using the water surface as a reference datum:

$$P_A = P_D + \text{losses in pressure vessel} \tag{A9}$$

4. The pressure vessel losses include energy lost by the supply air and by the discharge mixture in the pressure vessel. At a constant discharge rate and in the range of water depths encountered in the water

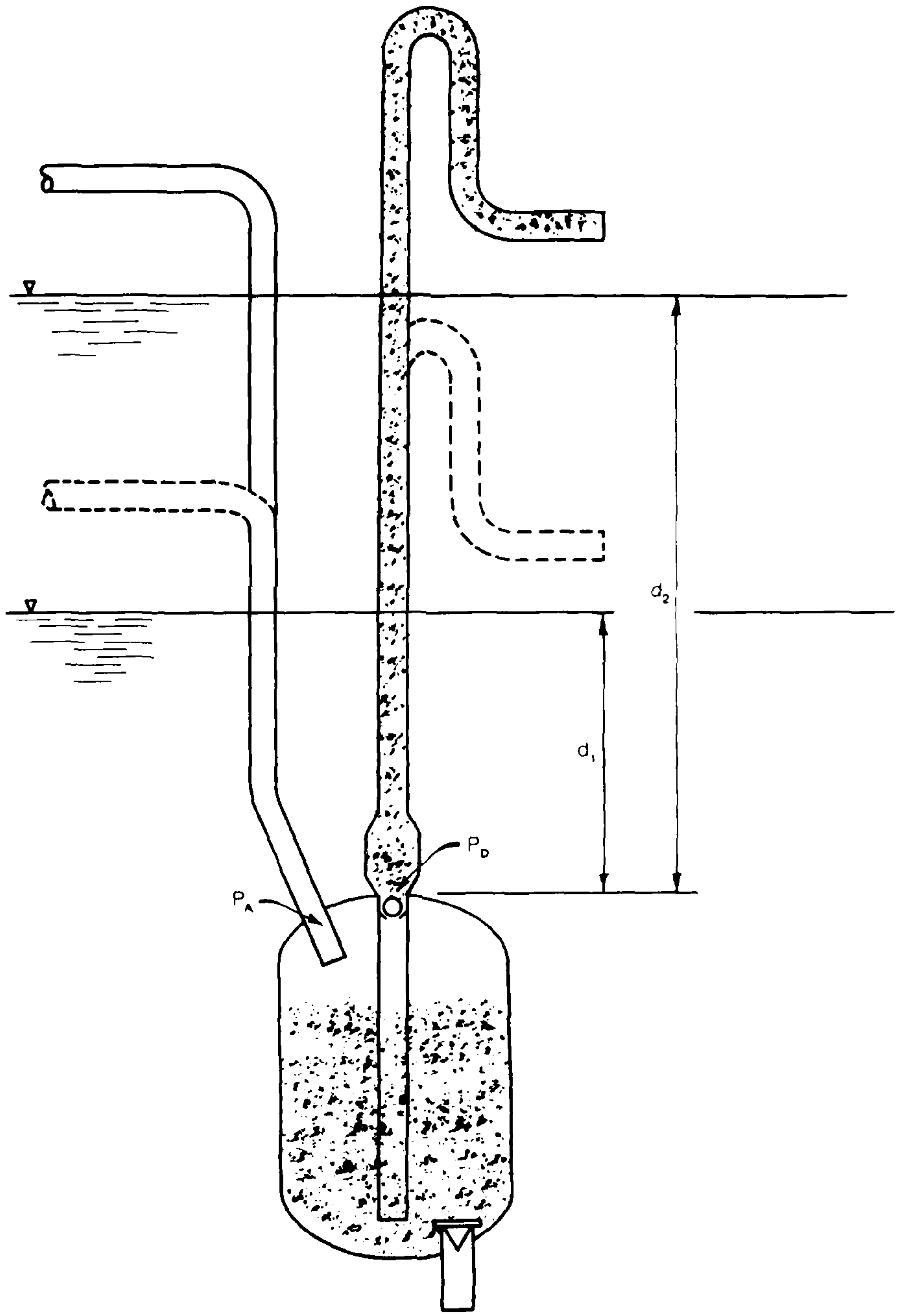


Figure A1. PNEUMA pressure vessel

tests, the pressure vessel losses may be assumed to be roughly constant. Therefore, Equation A9 can be expressed as:

$$P_A = P_D + \text{constant} \tag{A10}$$

5. If the PNEUMA pump is operating at a depth d, it can be shown from Bernoulli's law that:

$$P_D = d + \text{losses in discharge line} + \text{velocity head} + \text{discharge elevation} \tag{A11}$$

6. At a constant discharge rate, the velocity head will be constant. Since the discharge line length was fixed in the water tests, line losses were constant. Also, discharge elevation was constant. Equation A11 now becomes:

$$P_D = d + \text{constant} \tag{A12}$$

7. Substituting Equation A12 into Equation A10,

$$P_A = d + \text{constant} \tag{A13}$$

8. Equation A13 shows that with a few simplifying assumptions, P_A varies linearly with depth in a constant operating situation.

9. Air entering the pressure vessel at pressure P_A acts as a piston to force material into the discharge line. The volume of air entering the vessel at a given pressure must equal the volume of material forced into the discharge line. Therefore, if the same volume of material is pumped each cycle, the volume of air supplied will be the same for each cycle, regardless of changes in water depth. Call this air volume V. Then, if the PNEUMA pump is operated under constant conditions at two different depths, d_1 and d_2, as shown in Figure A1, the total amount of air supplied to the pump per cycle will have the following characteristics:

Depth d_1 -

$$\text{Average pressure} = P_{A1} = (d_1 + \text{constant})$$
$$\text{Total volume} = V \tag{A14}$$

Depth d_2 -

$$\text{Average pressure} = P_{A2} = (d_2 + \text{constant})$$
$$\text{Total volume} = V \tag{A15}$$

10. Assuming a constant air temperature, Boyle's law states, for a given gas sample:

$$P'V' = P''V'' \tag{A16}$$

11. Therefore, to determine the total air volumes V_1' and V_2' supplied in standard cubic feet at depths d_1 and d_2, substitute atmospheric pressure for P' in Equation A16. Then:

Depth d_1 -

$$P'V_1' = P_{A1}V \tag{A17}$$

Depth d_2 -

$$P'V'_2 = P_{A2}V \tag{A18}$$

12. Solving Equations A17 and A18 for V and equating the results:

$$\frac{P'V_1'}{P_{A1}} = \frac{P'V_2'}{P_{A2}} \tag{A19}$$

13. Substituting Equations A14 and A15, dividing by P' , and rearranging:

$$\frac{V_1'}{V_2'} = \frac{(d_1 + \text{constant})}{(d_2 + \text{constant})} \qquad \text{(A20)}$$

14. Equation A20 shows that, as a first approximation, the total volume of air in standard cubic feet supplied per cycle varies linearly as the water depth. If the air distributor is run at a constant speed, the time available for the total volume to flow into the pressure vessel will be constant regardless of depth. Therefore, the airflow rate in standard cubic feet per minute will also vary linearly with depth, as shown in Figure 23 (main text).

15. This relationship leads to an interesting series of calculations. The constant in Equation A20 is composed of:

$$\text{Constant} = \text{pressure vessel losses} + (\text{discharge line losses} + \text{velocity head} + \text{discharge elevation}) \qquad \text{(A21)}$$

Calling the pressure vessel losses "C," for a discharge water flow rate of 3400 gpm, Equation A21 can be simplified using available data and standard pipe loss relations:

$$\text{Constant} = C + (9.7 + 3.0 + 10.0) = C + (22.7) \qquad \text{(A22)}$$

Using the PNEUMA pump as a reference datum, the number in parentheses in Equation A22 should equal, roughly, the total discharge head shown in Appendix C in the water tests for similar flow rates, which it does. From Figure 23 (main text), the following values are obtained:

d = 20 ft   Airflow rate = 785 scfm

d = 30 ft   Airflow rate = 875 scfm

16. Substituting these values and Equation A22 into Equation A20,

$$\frac{785}{875} = \frac{20 + C + 22.7}{30 + C + 22.7}$$

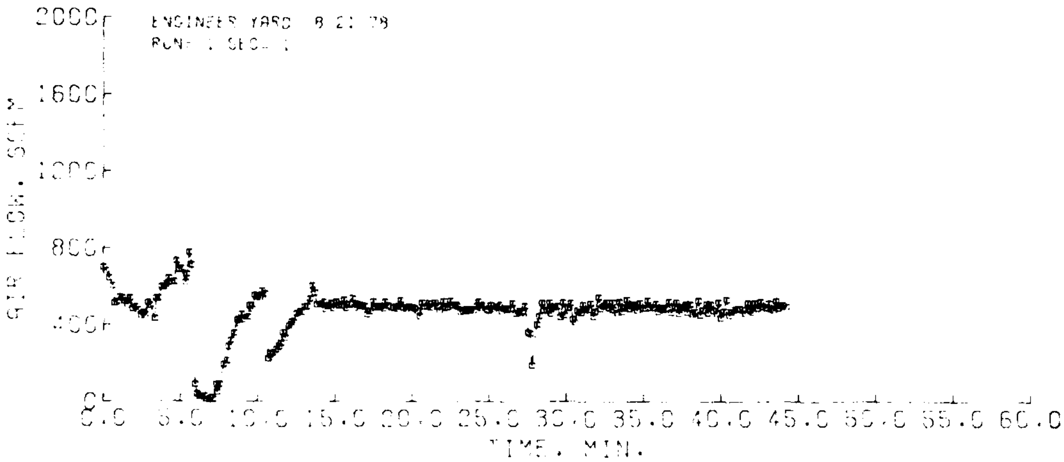
or

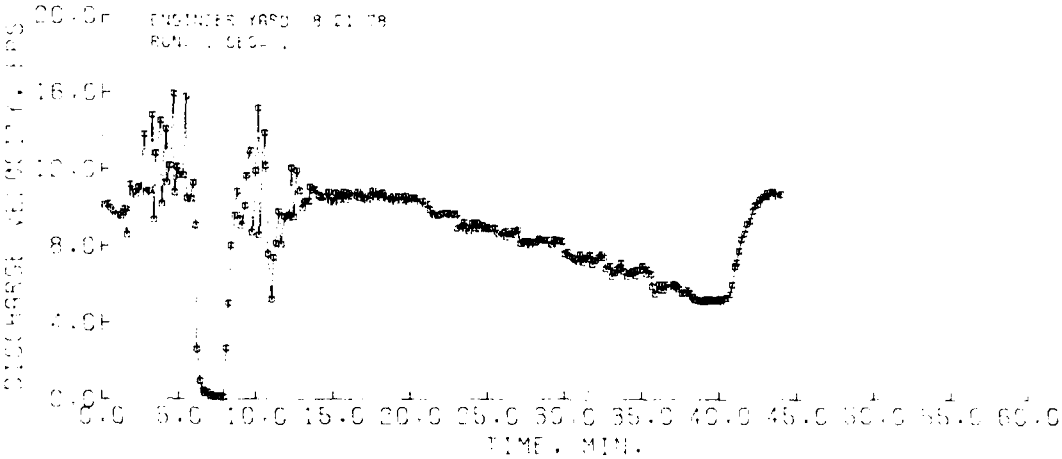
$$C = 44.5 \text{ ft of water} = \text{losses in pressure vessel}$$

17. While the exactness of these calculations is doubtful, they do serve to point out the relatively large magnitude of losses in the pressure vessel. They also indicate that efforts to improve the PNEUMA pump's efficiency should concentrate on reducing these losses.

Data Plots

18. The major portion of this appendix (Plates A1-A93) consists of plots of three measured parameters versus time: airflow rate supplied to the PNEUMA pump, discharge velocity, and discharge specific gravity. The plots are grouped in order of test location. The first group is for tests performed near the Wilmington District Engineer Yard, where only water was pumped. The next group describes tests done at Lock and Dam No. 1. The third group shows the Masonboro Inlet tests. At both of these sites, sand was pumped. The fourth group presents results of the MOTSU (Sunny Point) tests, where a loosely consolidated silty clay was pumped. In addition to the plots, each group contains a set of histograms. These histograms summarize the distribution of two parameters, discharge percent solids and in situ excavation rate, for selected portions of selected runs. The run portions selected were those when the pump was discharging a relatively high density slurry. Thus, the histograms represent "best performances" of the PNEUMA pump during these tests. In the MOTSU (Sunny Point) tests, excavation rate was expressed in terms of an equivalent rate of material with bulk specific gravity 1.23.


ENGINEERS YARD 8 21 78
RUN 1 SEC 1
TIME, MIN.


ENGINEERS YARD 8 21 78
RUN 1 SEC 1
TIME, MIN.

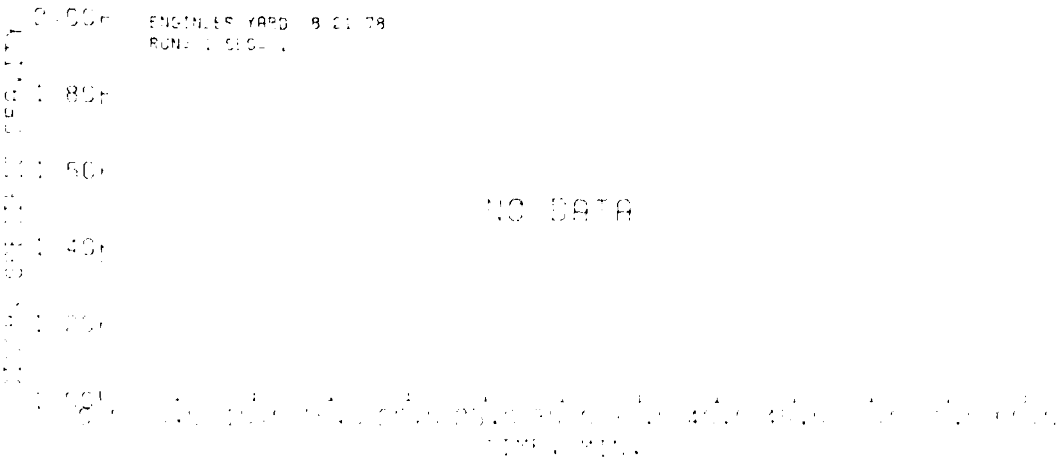
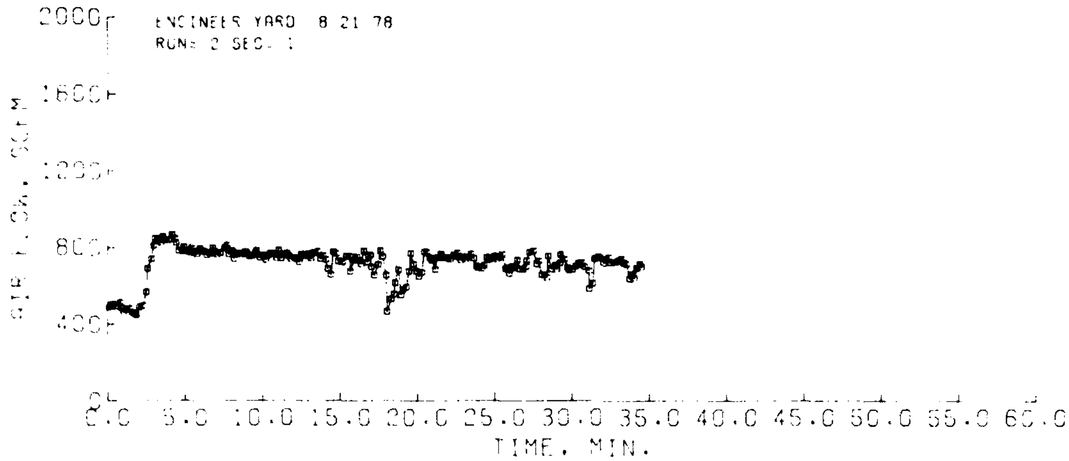
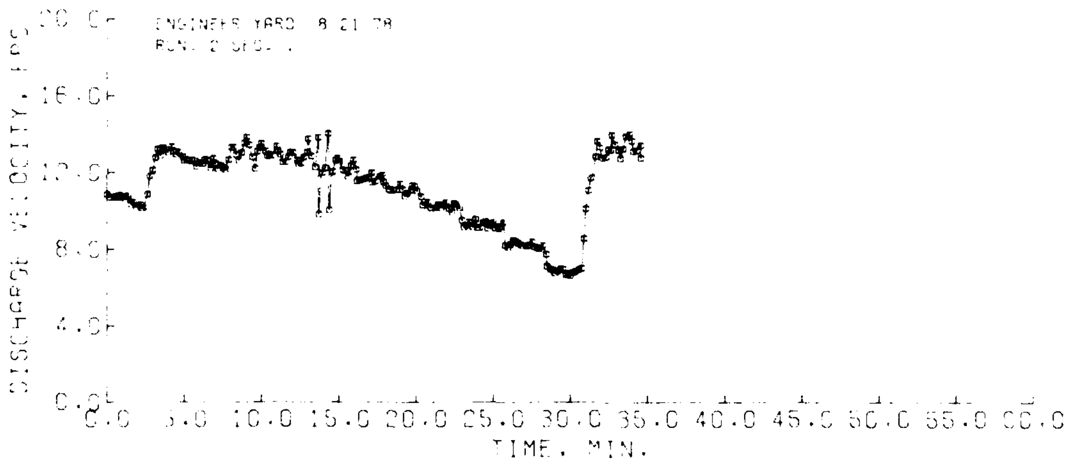

ENGINEERS YARD 8 21 78
RUN 1 SEC 1
NO DATA

PLATE A1


ENGINEERS YARD 8 21 78
RUN= 2 SEC. 1
TIME, MIN.


ENGINEERS YARD 8 21 78
RUN= 2 SEC. 1
TIME, MIN.

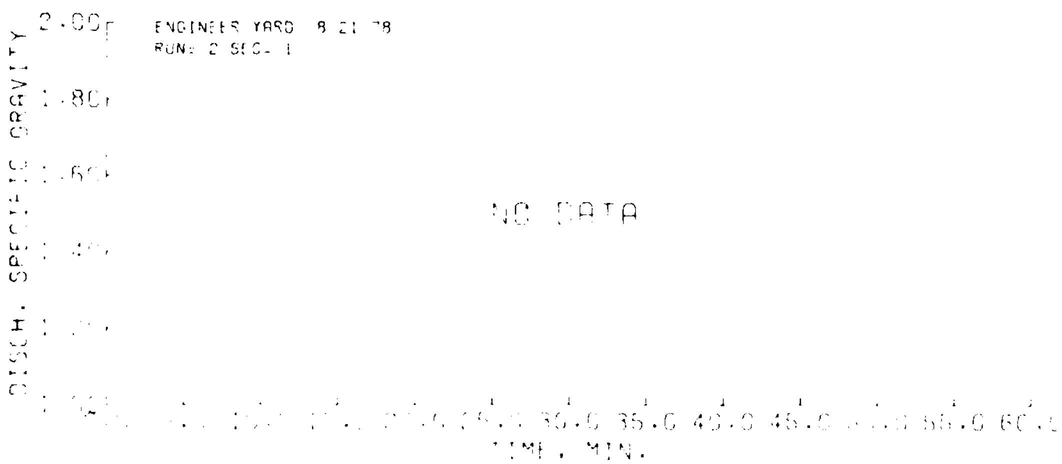
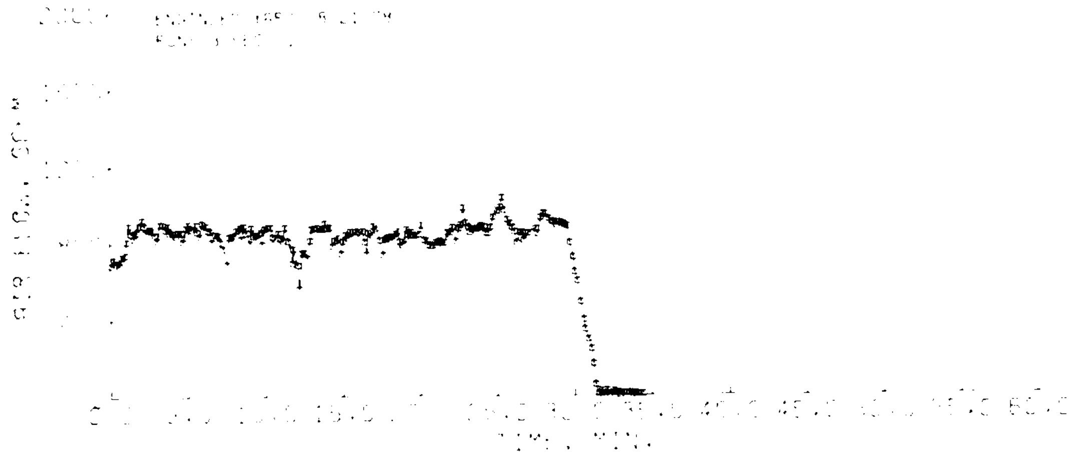
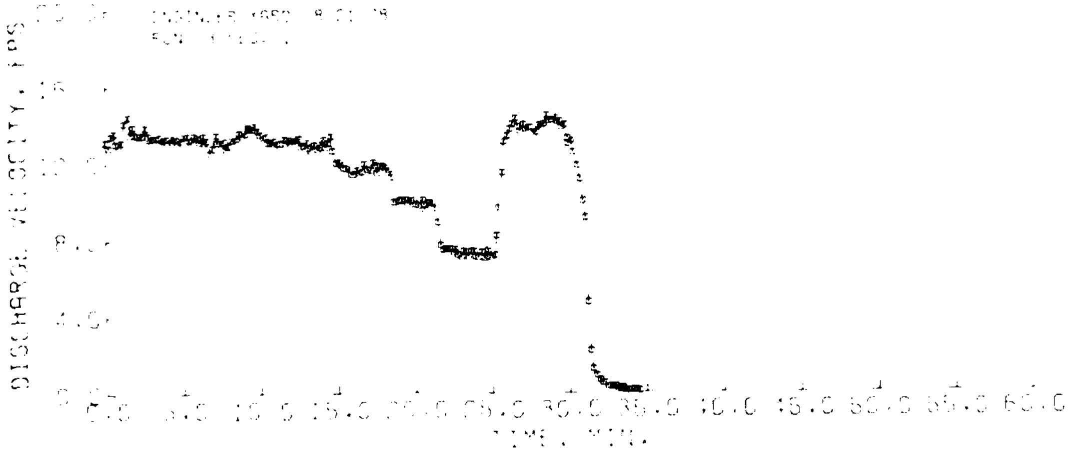

ENGINEERS YARD 8 21 78
RUN= 2 SEC. 1
DISCH. SPECIFIC GRAVITY
NO DATA
TIME, MIN.

PLATE A2





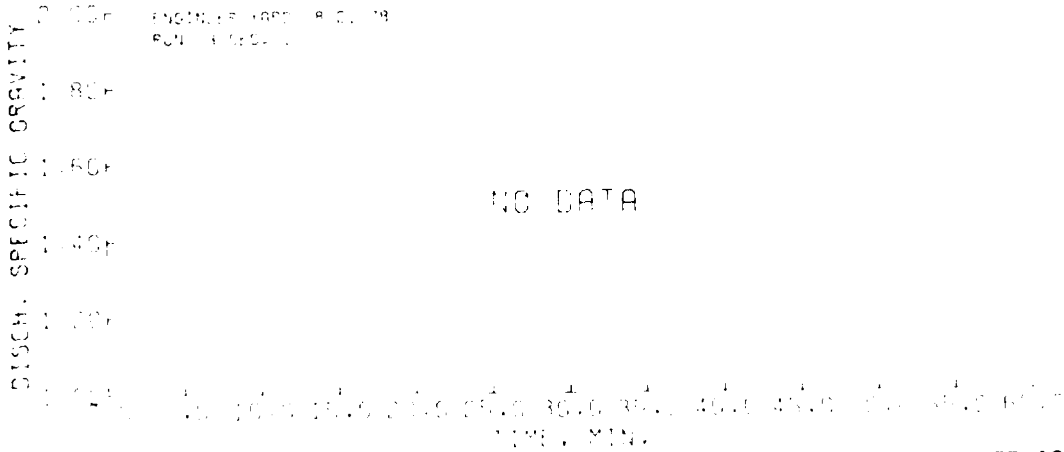
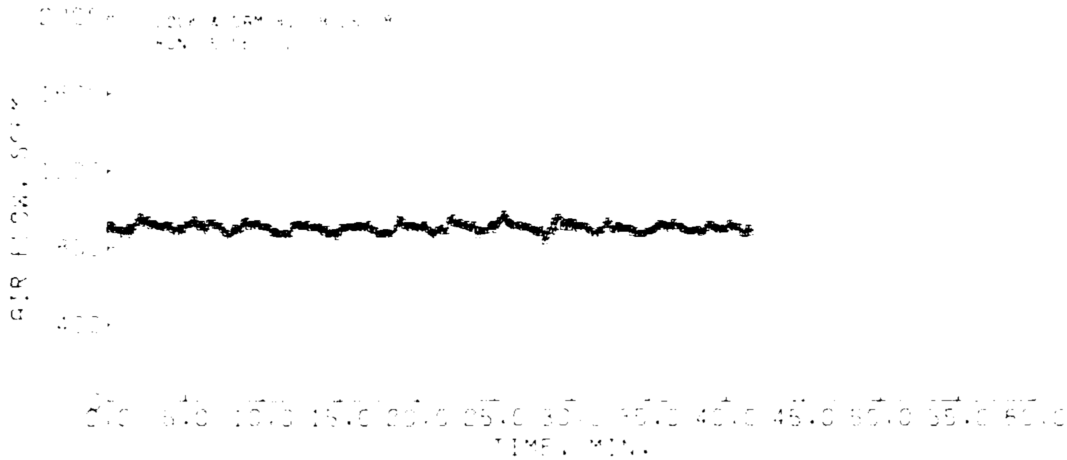
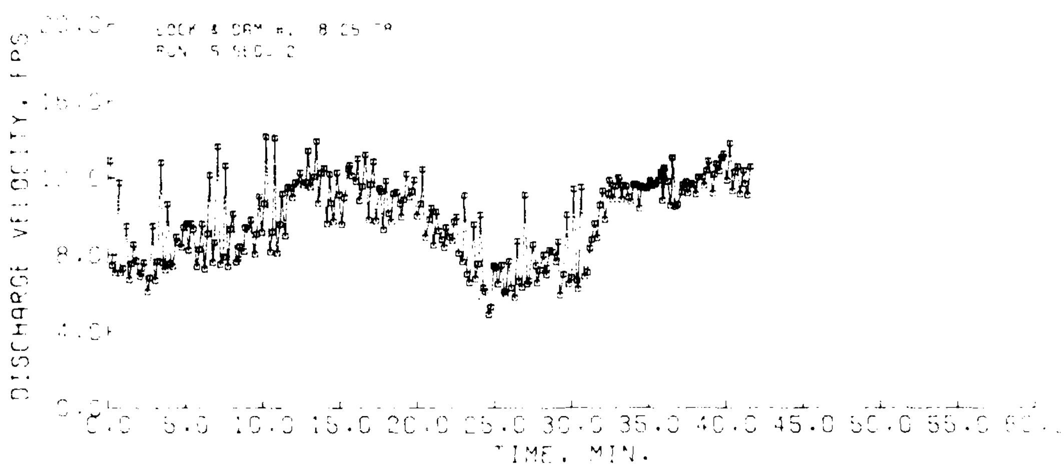


PLATE A3





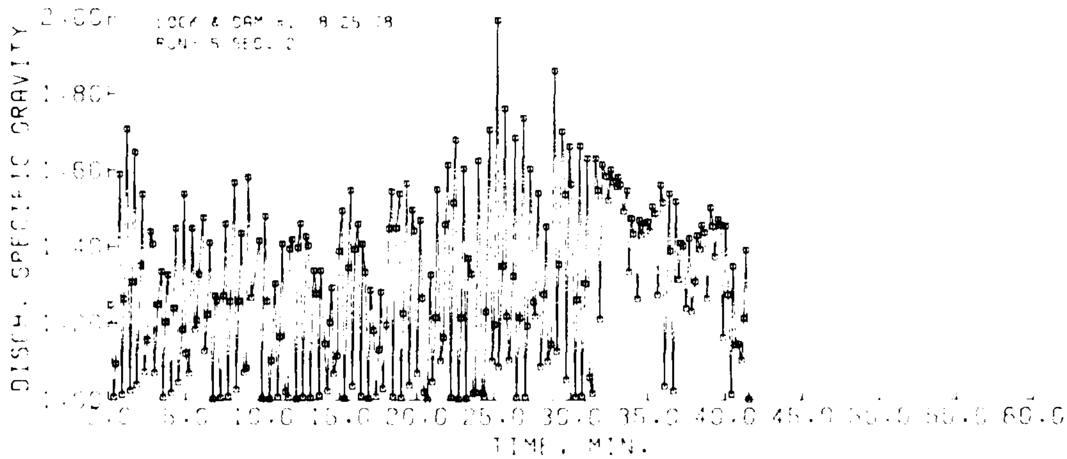
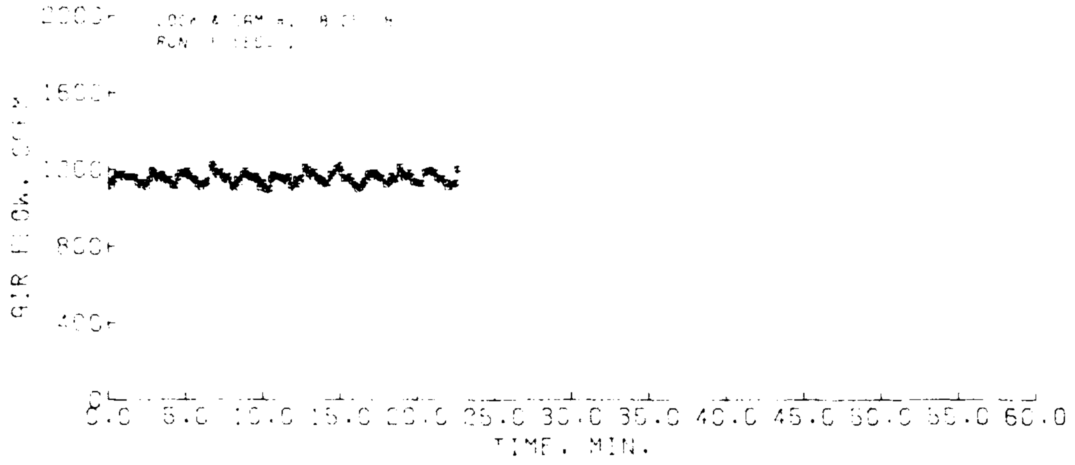
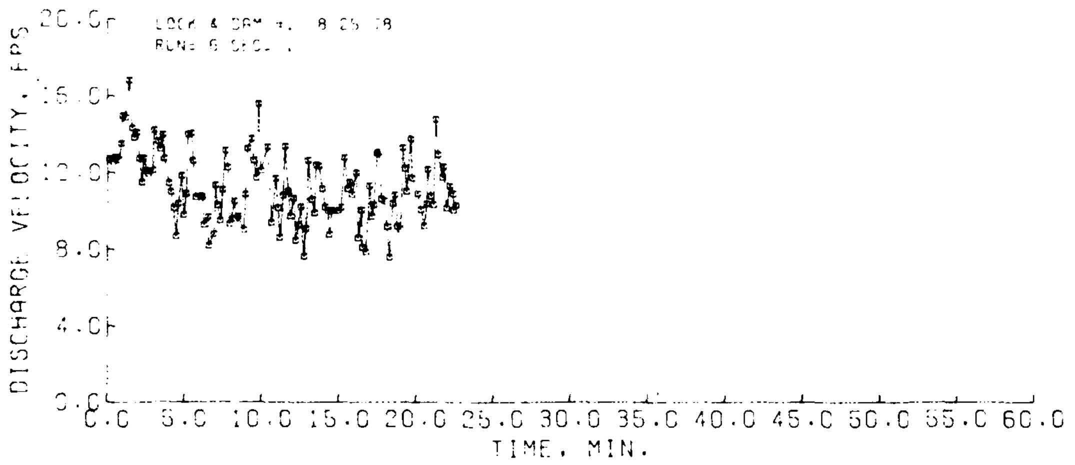


PLATE A4


LOCK & DAM #1 8 25 78
RUN= 6 SEQ= 1
AIR FLOW, SCFM
TIME, MIN.


LOCK & DAM #1 8 25 78
RUN= 6 SEQ= 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

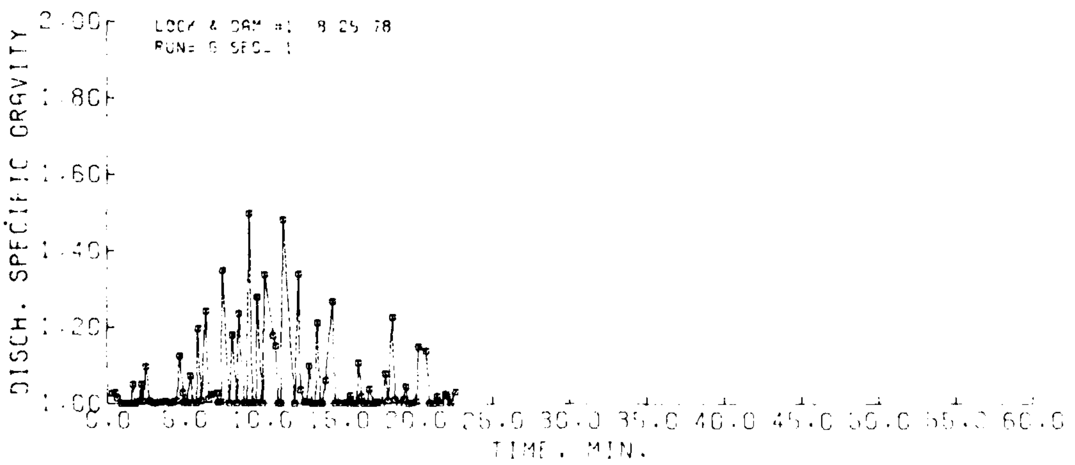
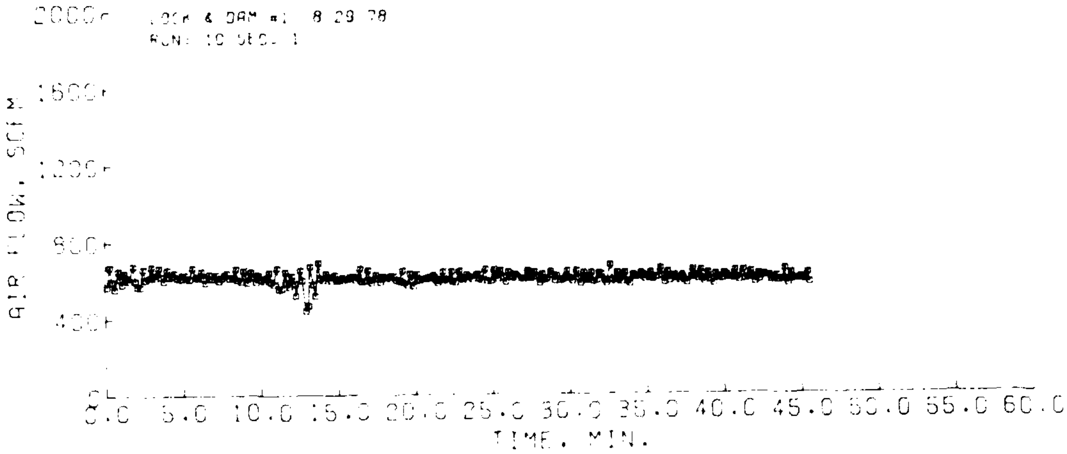
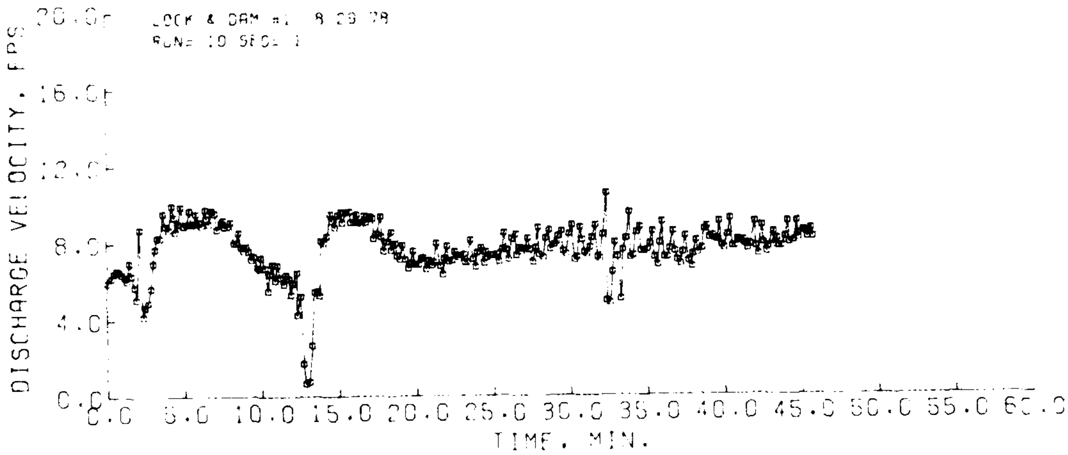

LOCK & DAM #1 8 25 78
RUN= 6 SEQ= 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A5


LOCK & DAM #1 8 29 78
RUN: 10 SEC: 1
AIR FLOW, SCFM
TIME, MIN.


LOCK & DAM #1 8 29 78
RUN: 10 SEC: 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

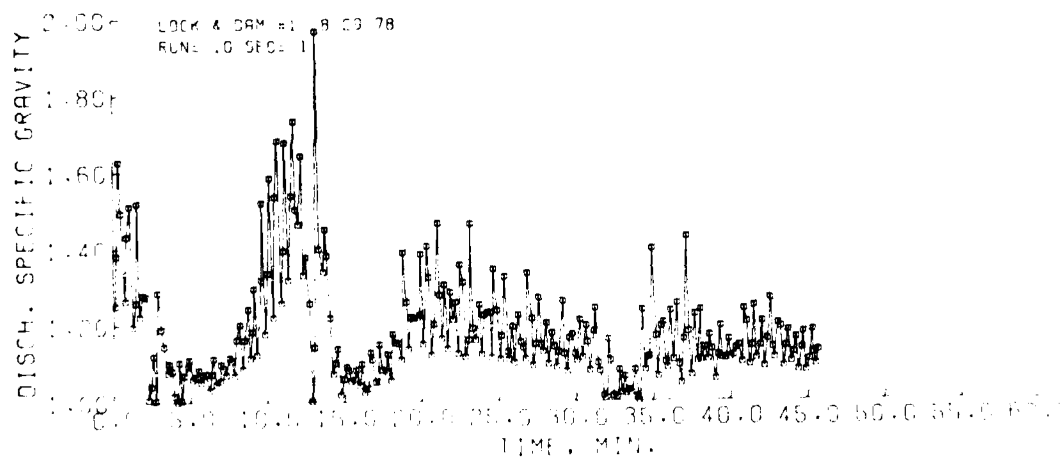

LOCK & DAM #1 8 29 78
RUN: 10 SEC: 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A6


30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
PERCENT SOLIDS

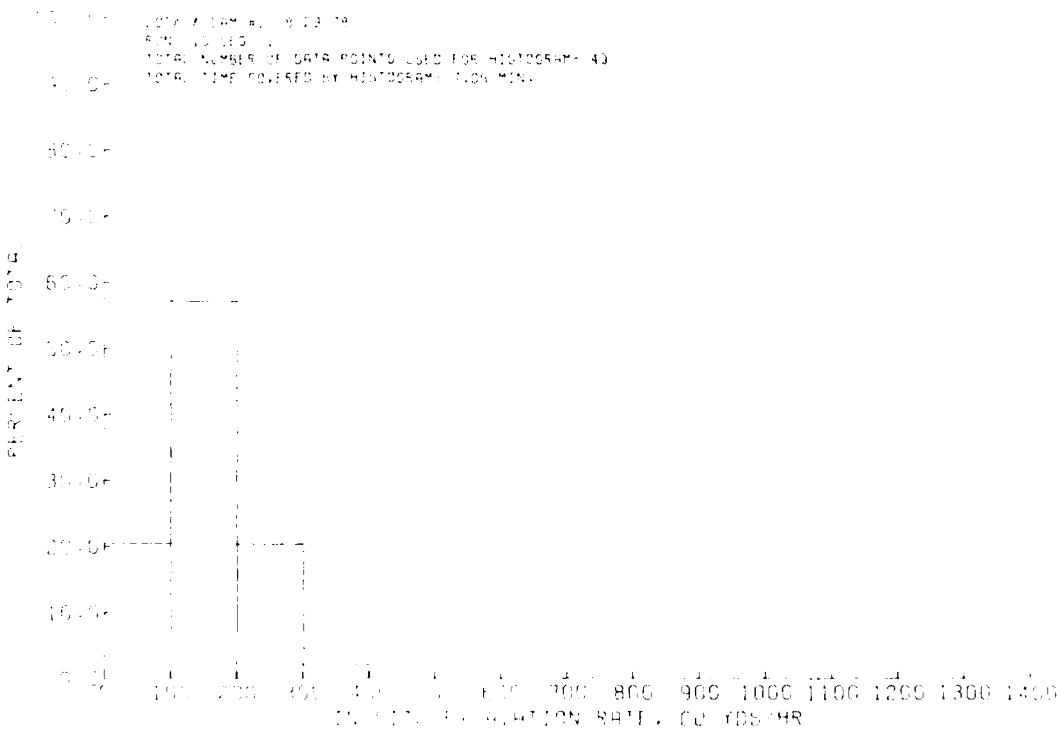
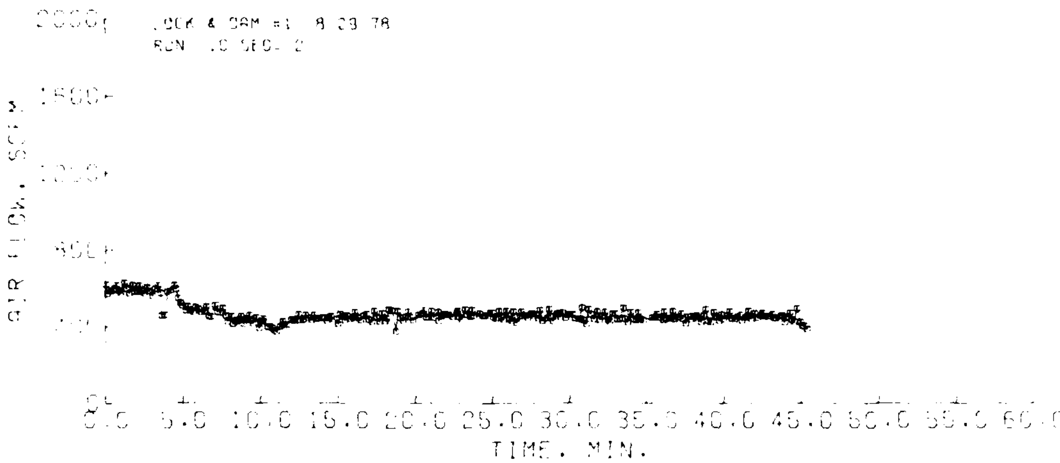
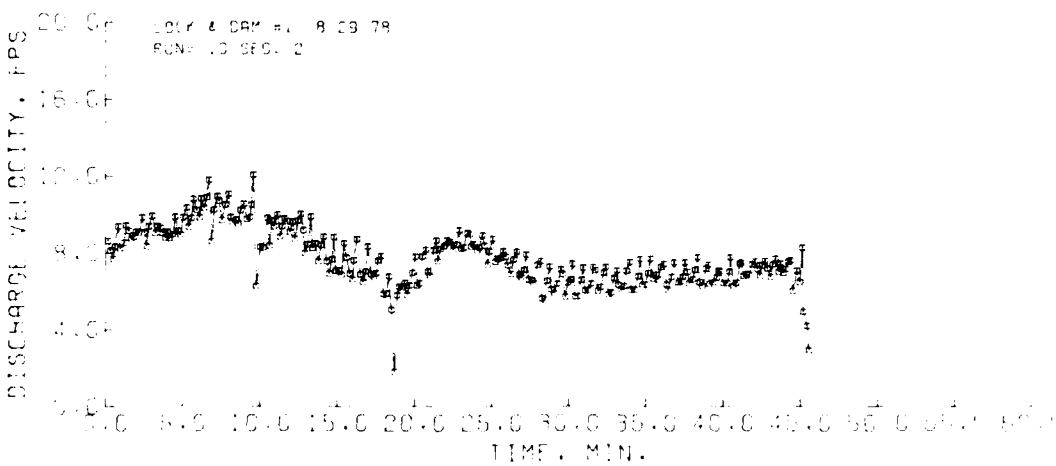

TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM: 43
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
700 800 900 1000 1100 1200 1300
RATE, CU YDS/HR

PLATE A7


TIME, MIN.


DISCHARGE VELOCITY, FPS
TIME, MIN.

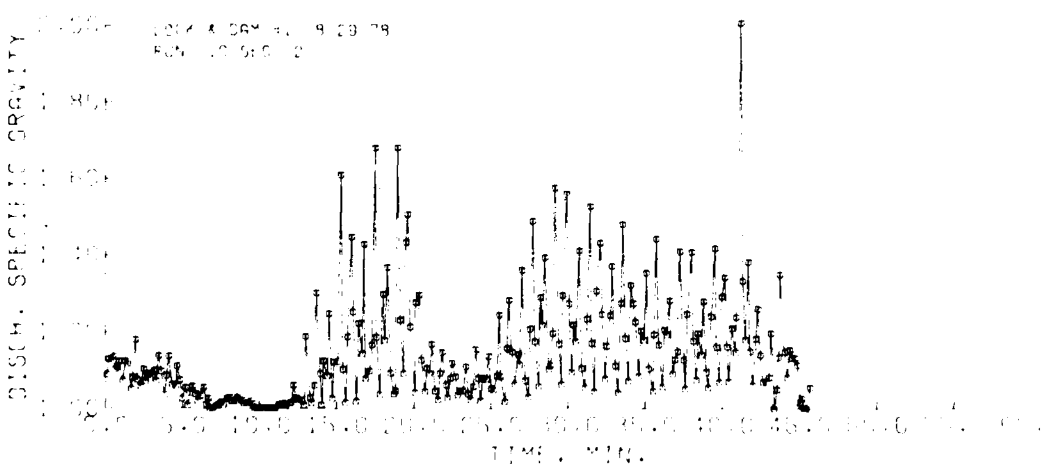
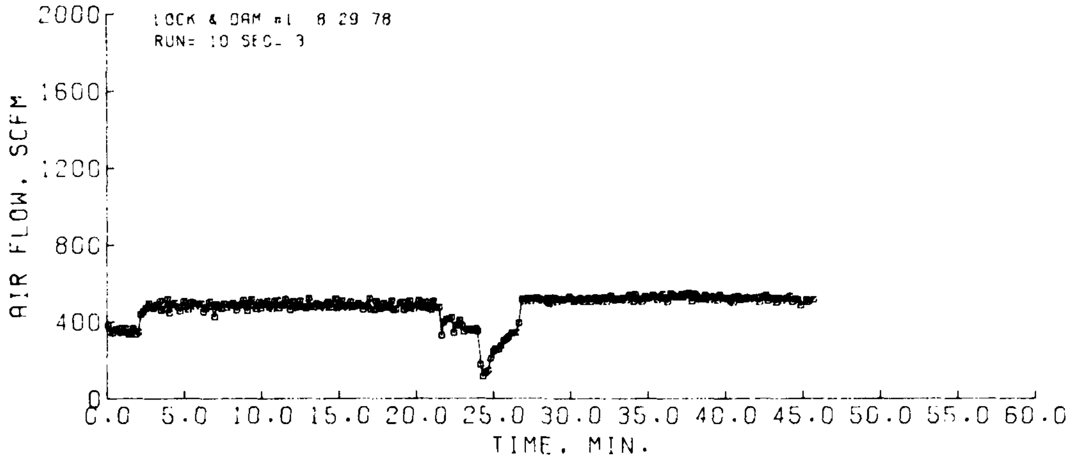
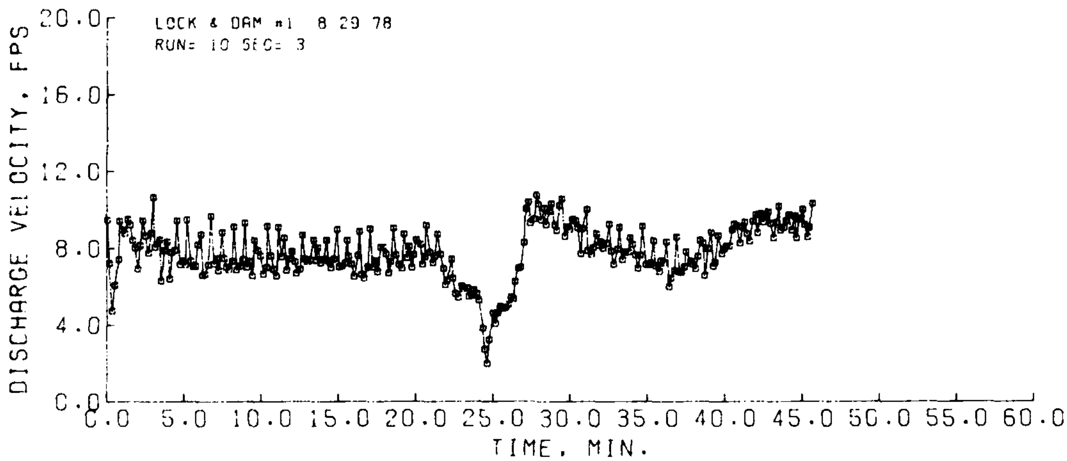

DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A8


LOCK & DAM #1 8 29 78
RUN= 10 SEC= 3
AIR FLOW, SCFM
TIME, MIN.


LOCK & DAM #1 8 29 78
RUN= 10 SEC= 3
DISCHARGE VELOCITY, FPS
TIME, MIN.

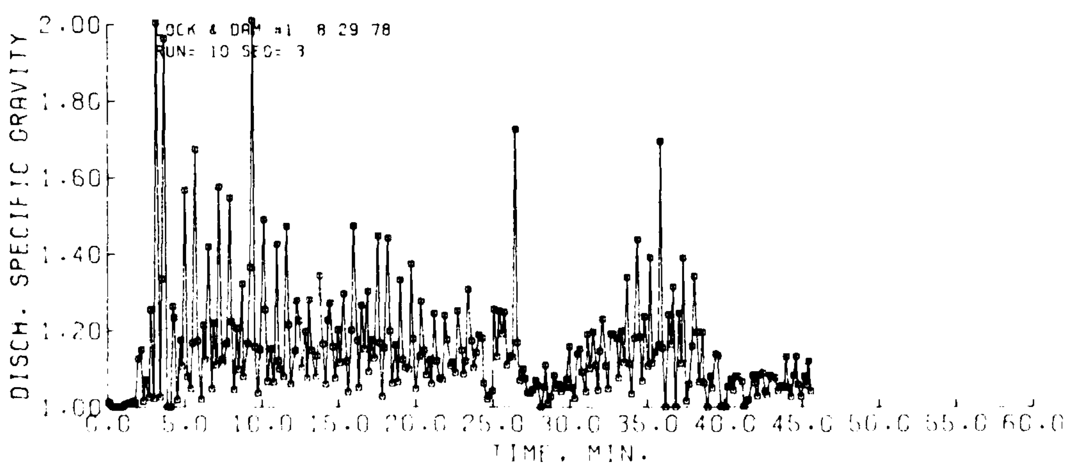

LOCK & DAM #1 8 29 78
RUN= 10 SEC= 3
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A9

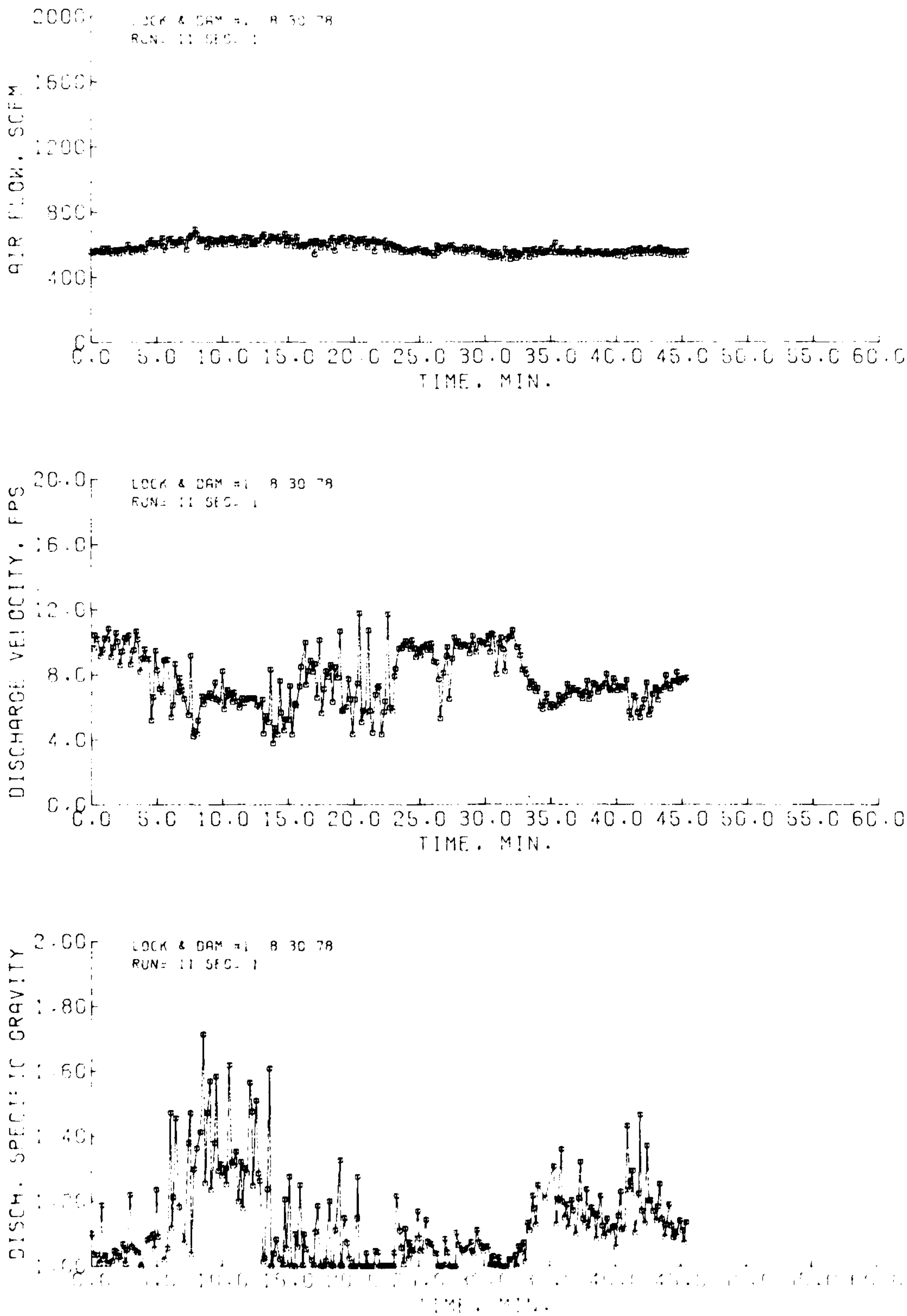
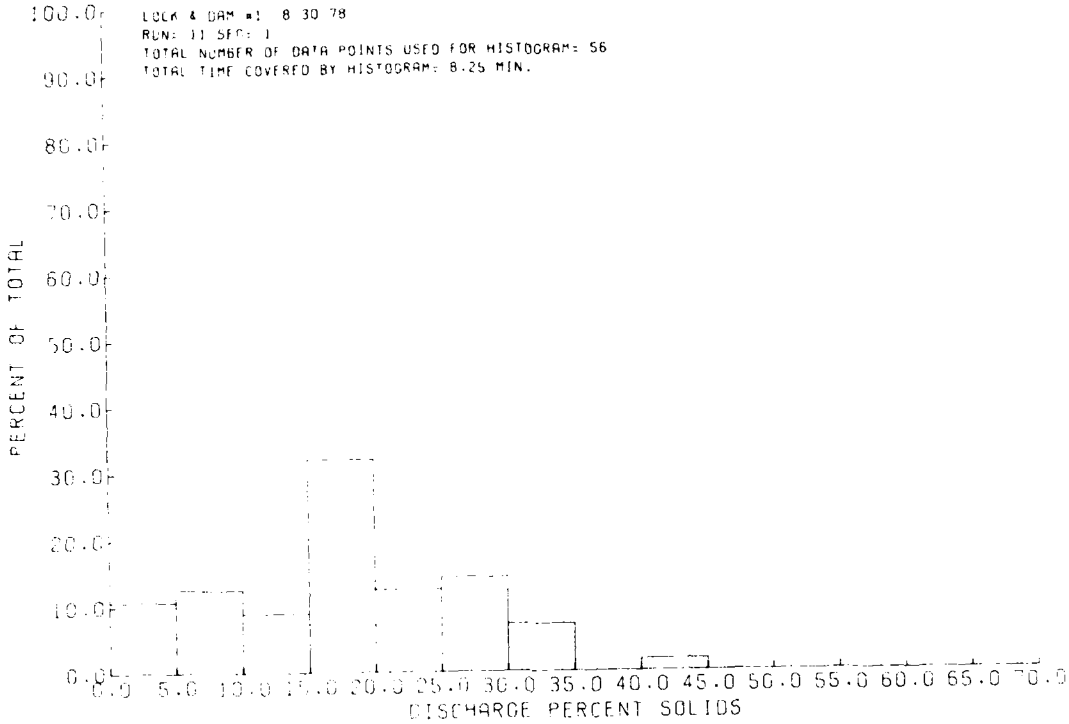

LOCK & DAM #1 8 30 78
RUN= 11 SEC= 1
AIR FLOW, SCFM
TIME, MIN.
LOCK & DAM #1 8 30 78
RUN= 11 SEC= 1
DISCHARGE VELOCITY, FPS
TIME, MIN.
LOCK & DAM #1 8 30 78
RUN= 11 SEC= 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A10


LOCK & DAM #1 8 30 78
RUN: 11 SEC: 1
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM: 56
TOTAL TIME COVERED BY HISTOGRAM: 8.25 MIN.
PERCENT OF TOTAL
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
DISCHARGE PERCENT SOLIDS

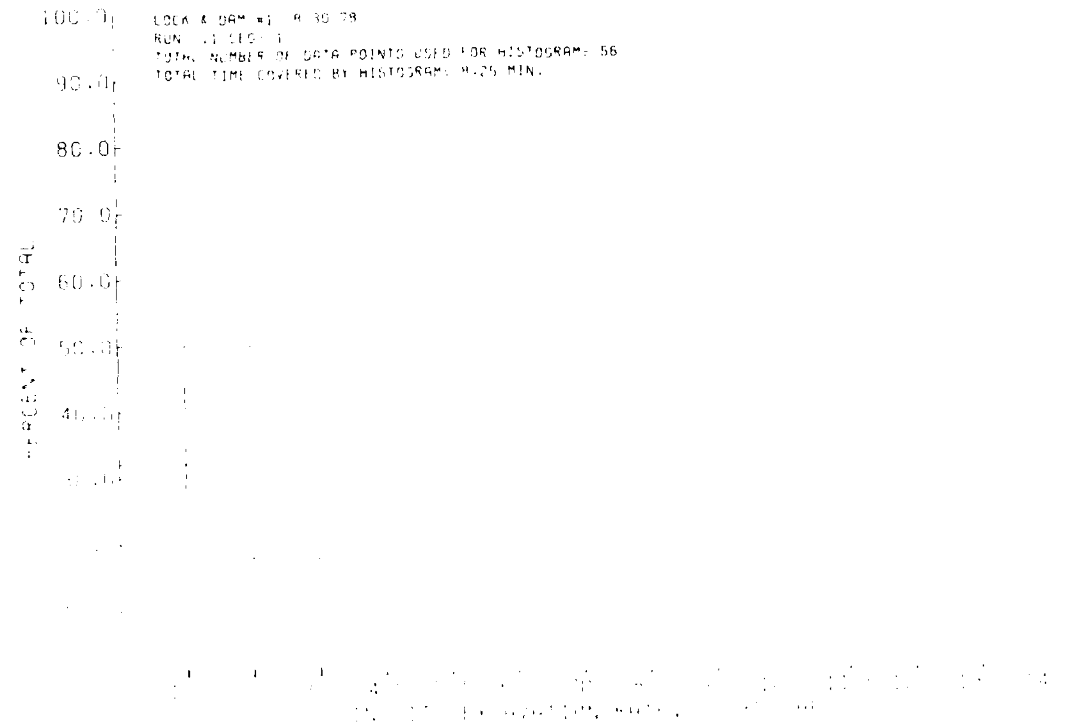
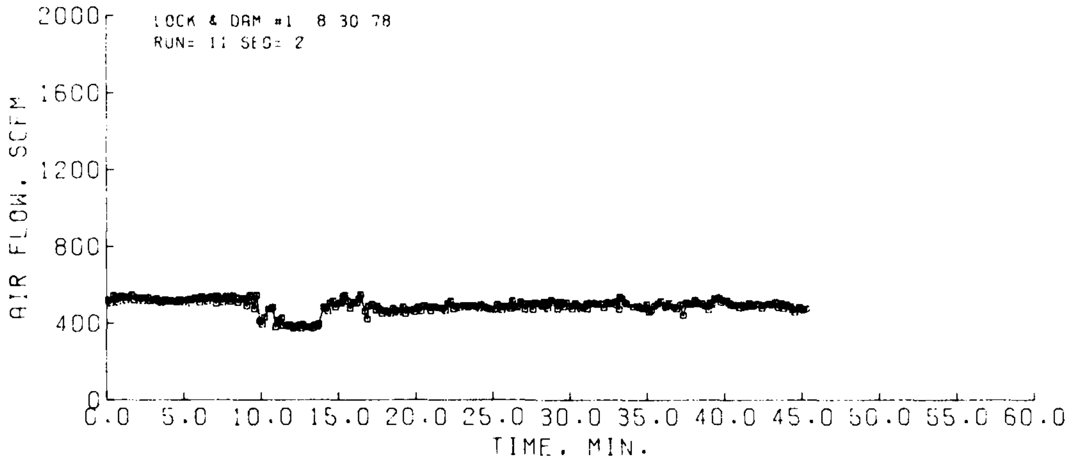
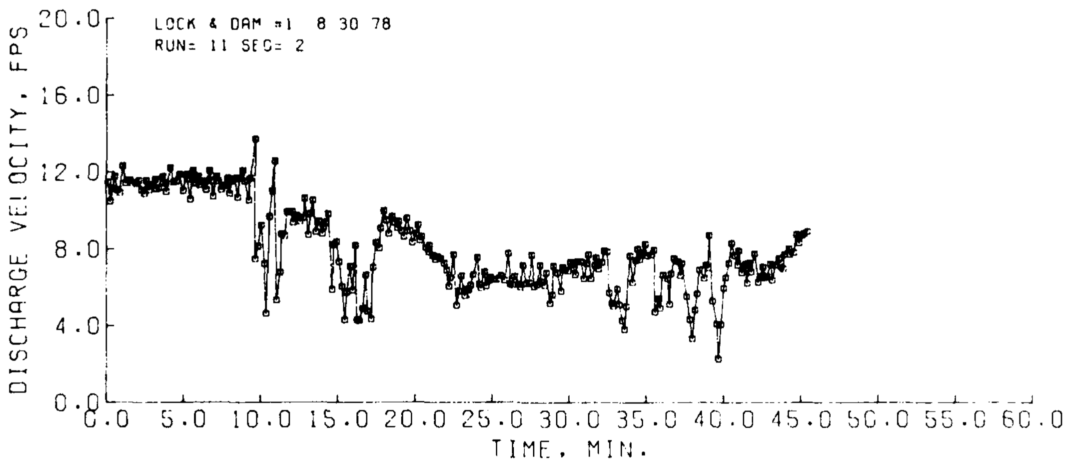

LOCK & DAM #1 8 30 78
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM: 56
TOTAL TIME COVERED BY HISTOGRAM: 8.25 MIN.
90.0
80.0
70.0
60.0

PLATE A11


LOCK & DAM #1 8 30 78
RUN= 11 SEG= 2
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


LOCK & DAM #1 8 30 78
RUN= 11 SEG= 2
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

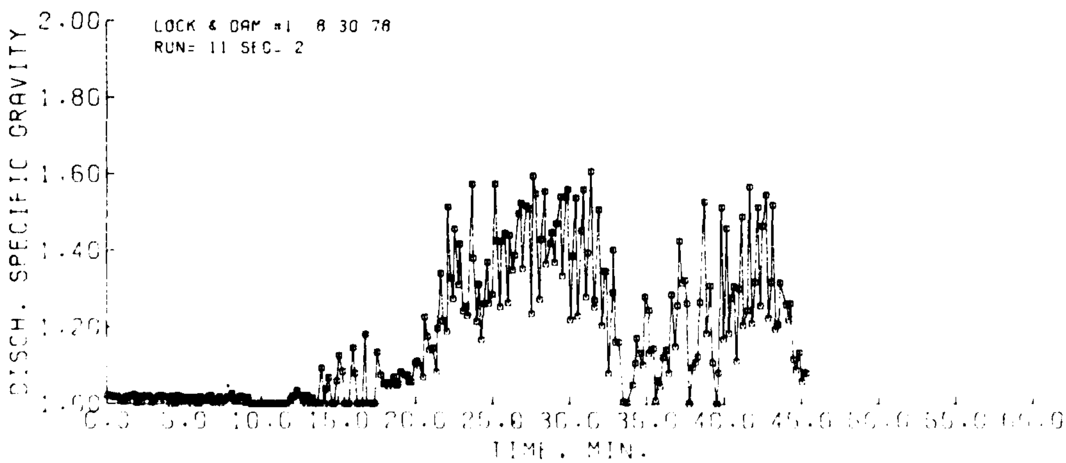
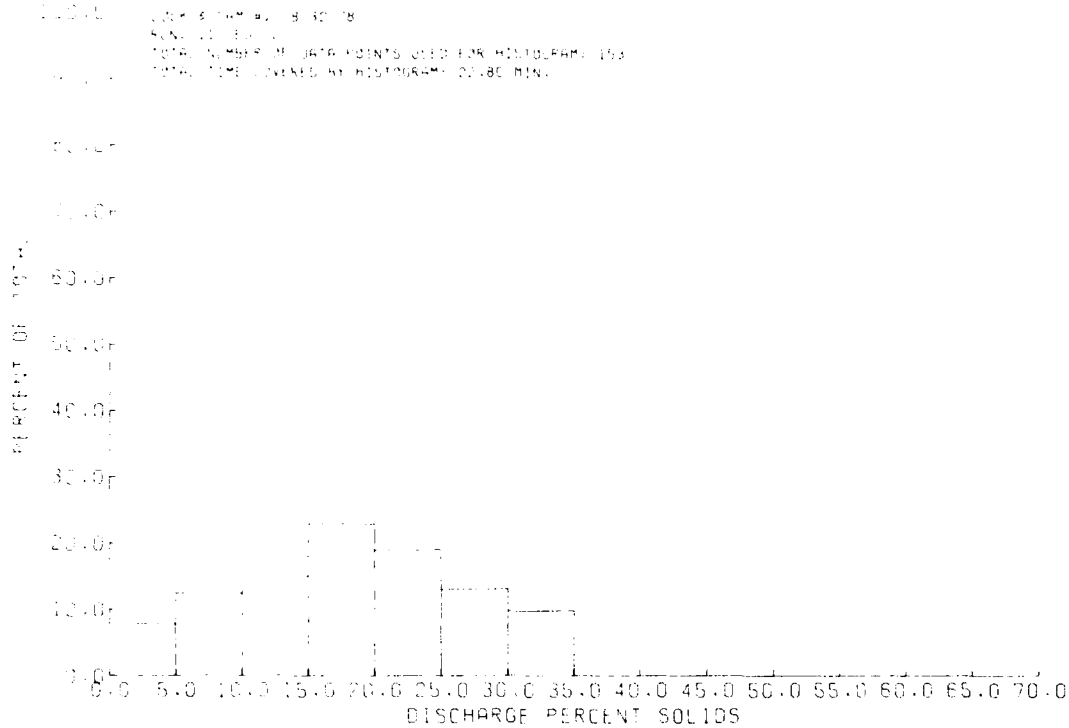

LOCK & DAM #1 8 30 78
RUN= 11 SEG= 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A12


TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 153
TOTAL TIME COVERED BY HISTOGRAM= 22.80 MIN.
60.0
50.0
40.0
30.0
20.0
10.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
DISCHARGE PERCENT SOLIDS

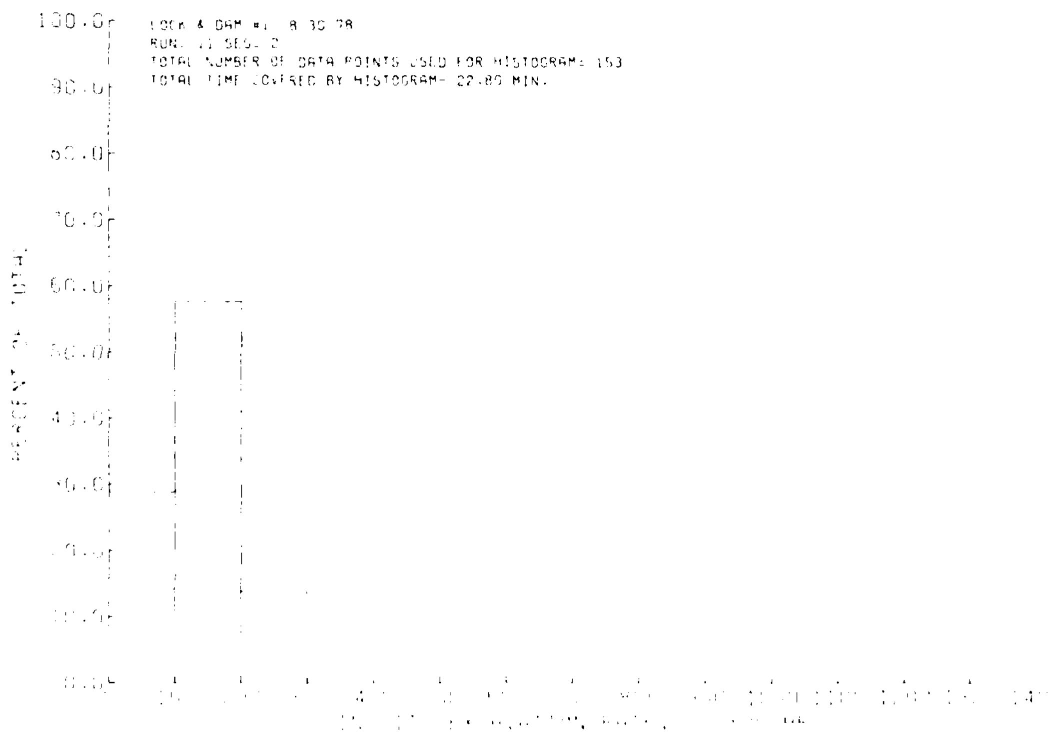
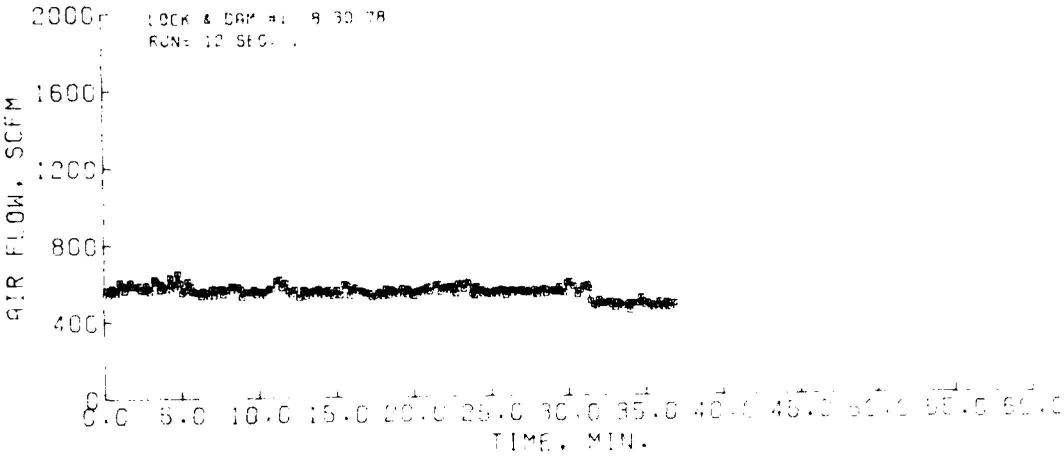
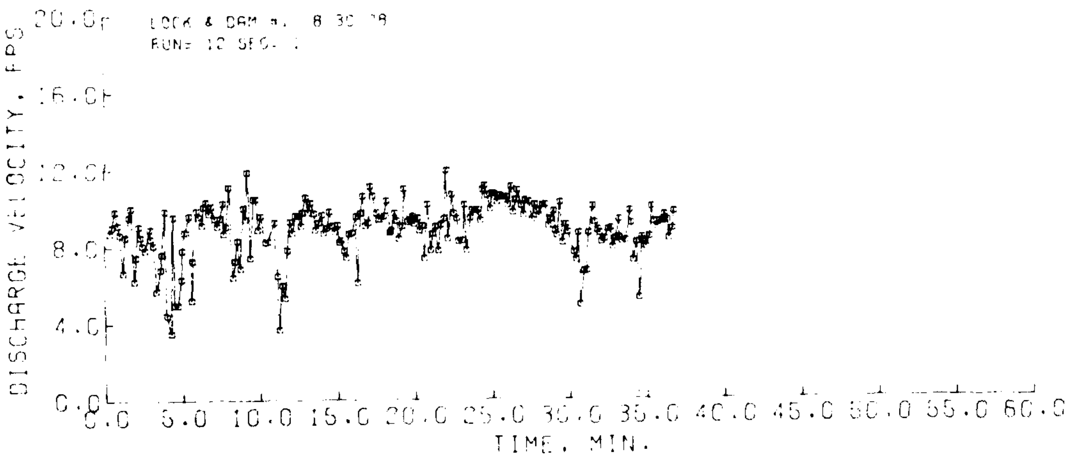

100.0
LOCK & DAM #1 8 30 78
RUN 11 SEG 2
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 153
TOTAL TIME COVERED BY HISTOGRAM= 22.80 MIN.
90.0
80.0
70.0
60.0
50.0

PLATE A13


LOCK & DAM #1 8 30 78
RUN= 12 SEC. 1
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


LOCK & DAM #1 8 30 78
RUN= 12 SEC. 1
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

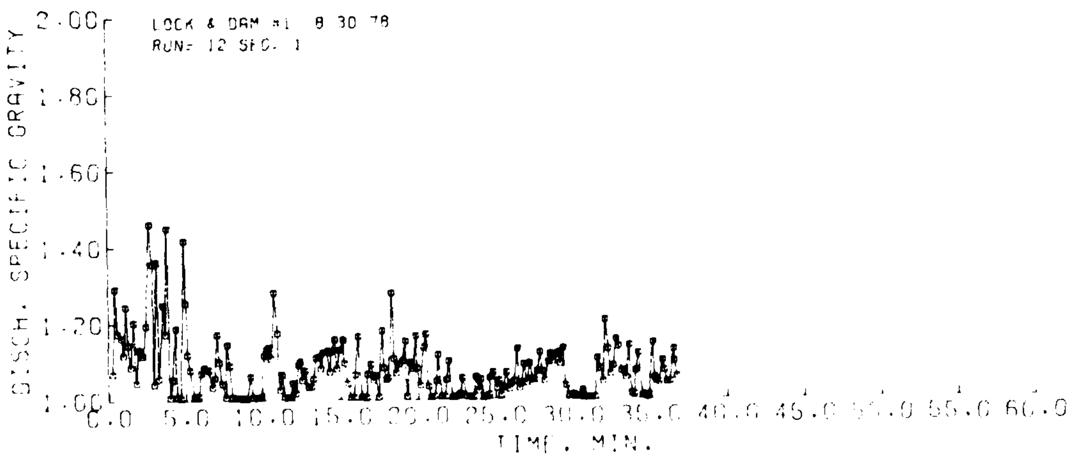
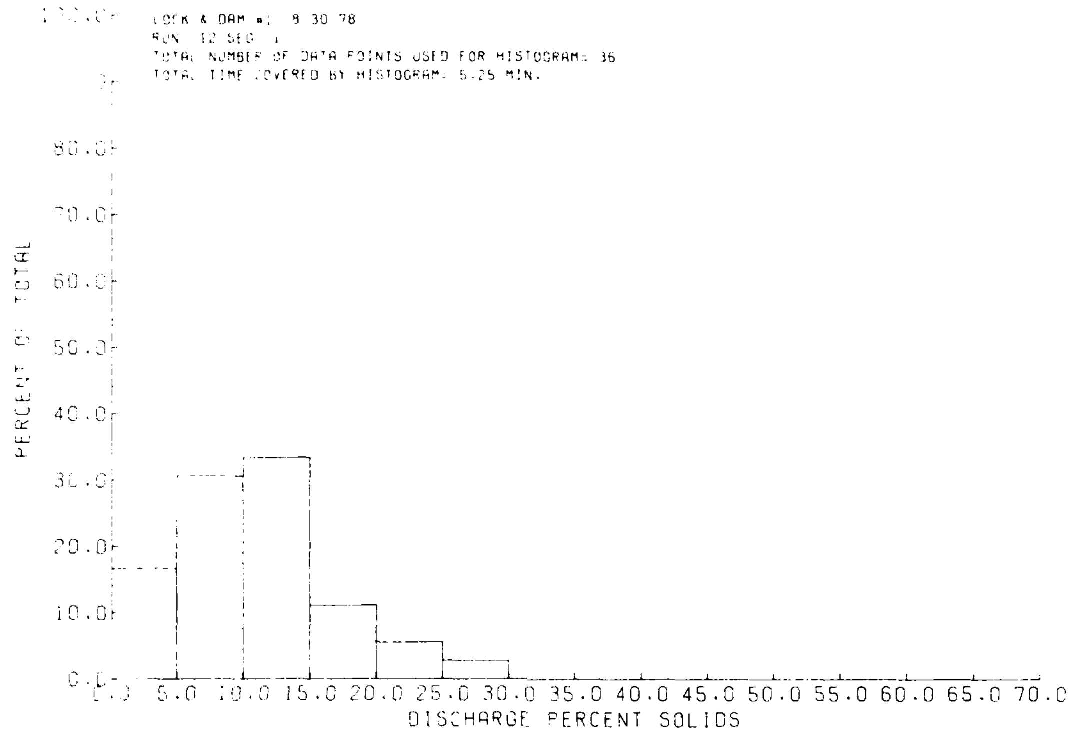

LOCK & DAM #1 8 30 78
RUN= 12 SEC. 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A14


LOCK & DAM #1 8 30 78
RUN: 12 SEG 1
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 36
TOTAL TIME COVERED BY HISTOGRAM= 5.25 MIN.
PERCENT OF TOTAL
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
DISCHARGE PERCENT SOLIDS

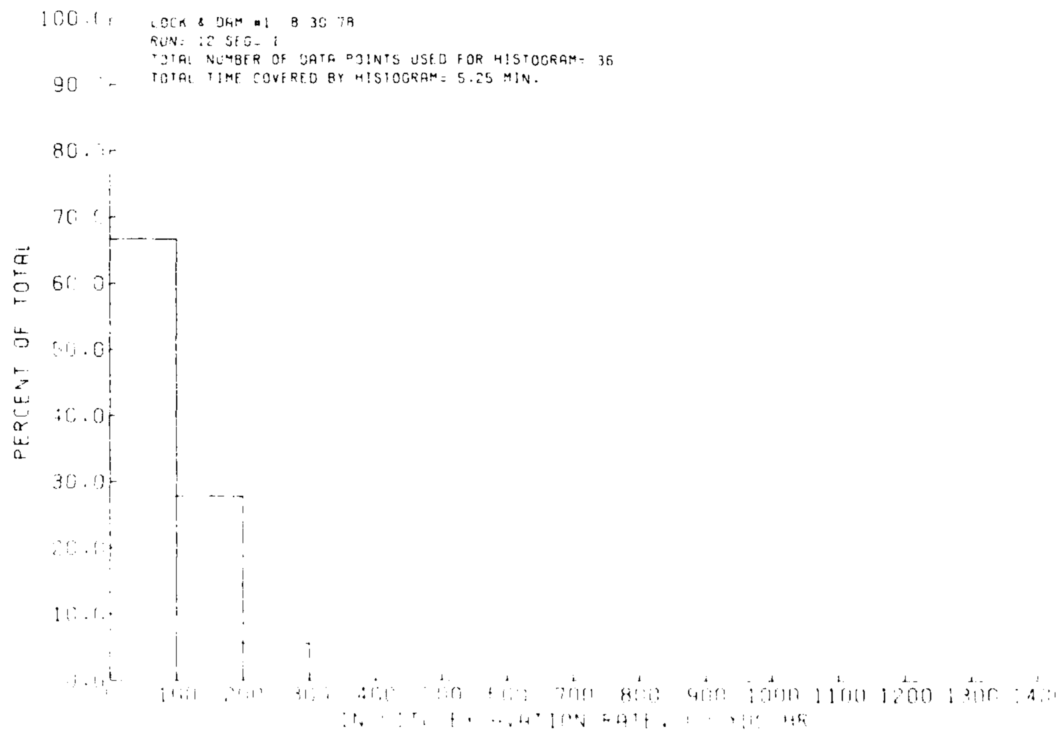
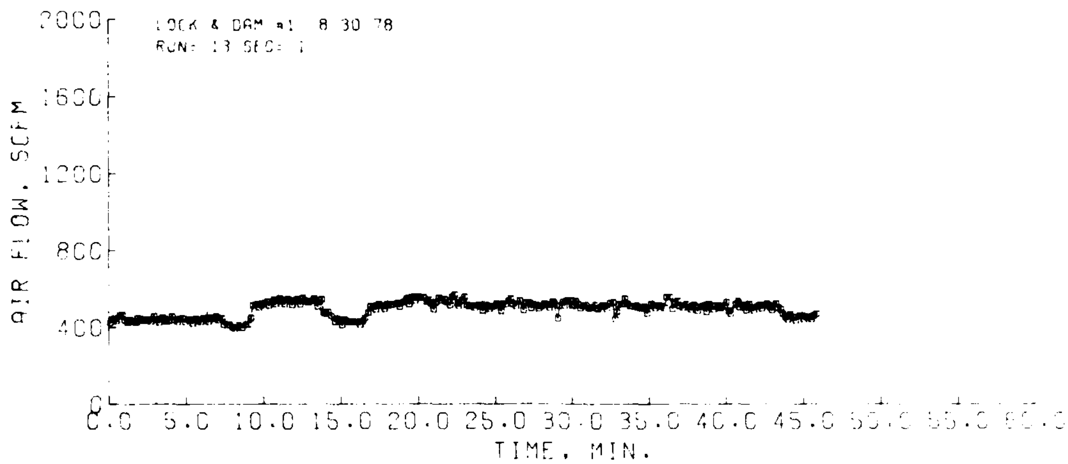
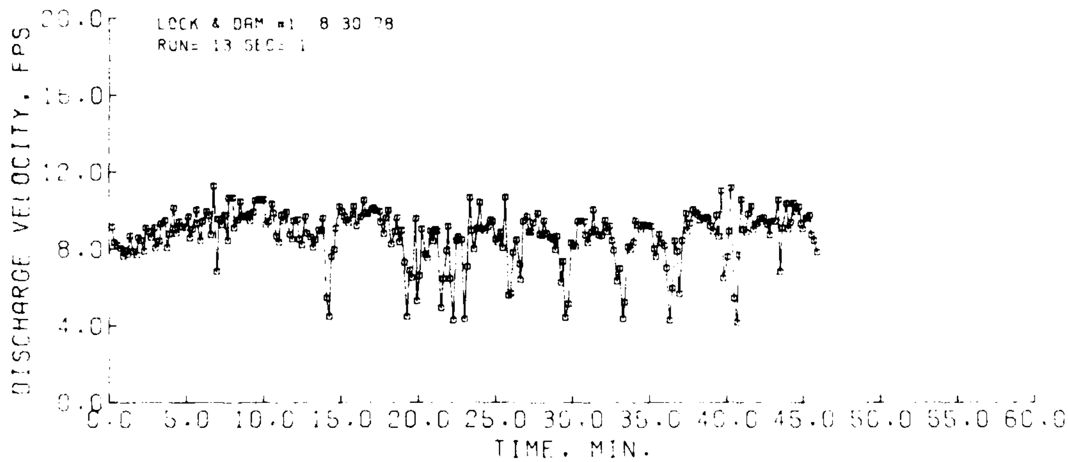

LOCK & DAM #1 8 30 78
RUN: 12 SEG 1
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 36
TOTAL TIME COVERED BY HISTOGRAM= 5.25 MIN.
100.0
90
80.
PERCENT OF TOTAL
30.0
100 200 700 800 900 1000 1100 1200

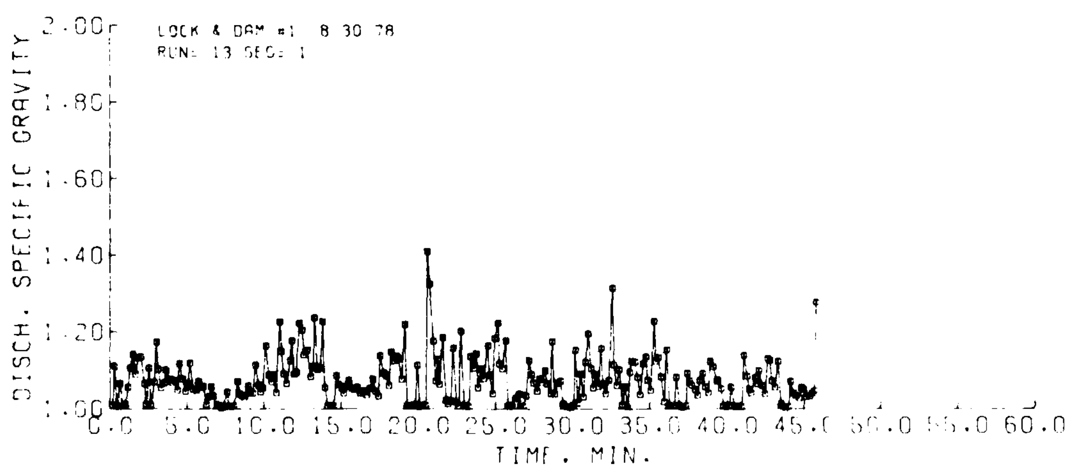
PLATE A15



LOCK & DAM #1 8 30 78
RUN= 13 SEC= 1
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

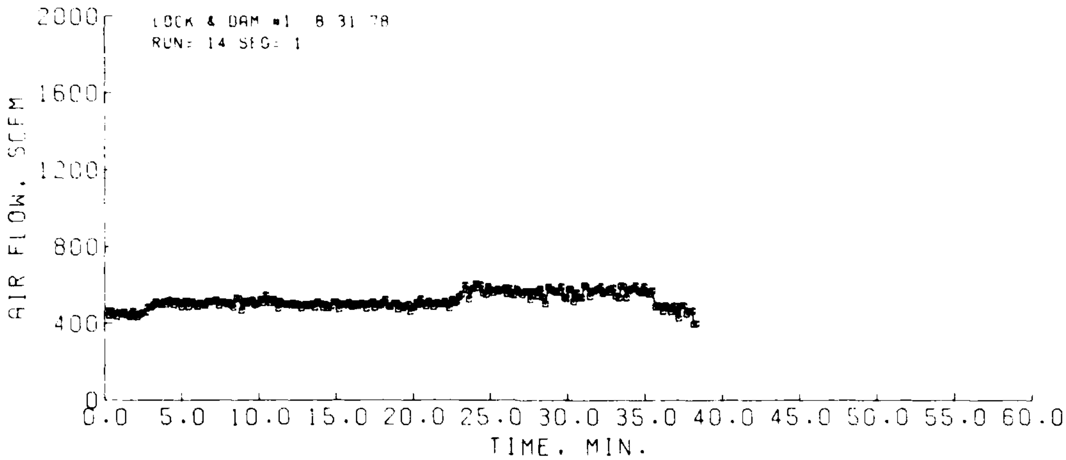


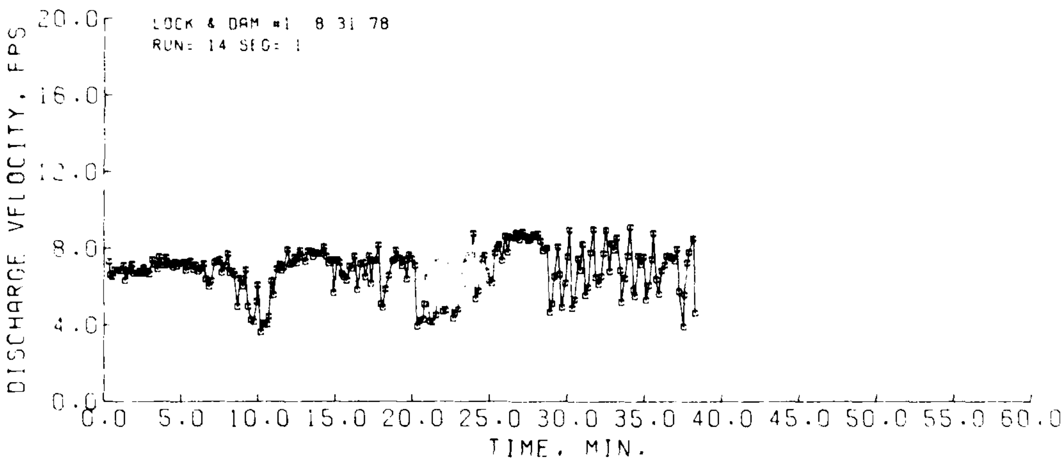
LOCK & DAM #1 8 30 78
RUN= 13 SEC= 1
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.



LOCK & DAM #1 8 30 78
RUN= 13 SEC= 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A16


LOCK & DAM #1 8 31 78
RUN: 14 SEG: 1
AIR FLOW, SCFM
TIME, MIN.


LOCK & DAM #1 8 31 78
RUN: 14 SEG: 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

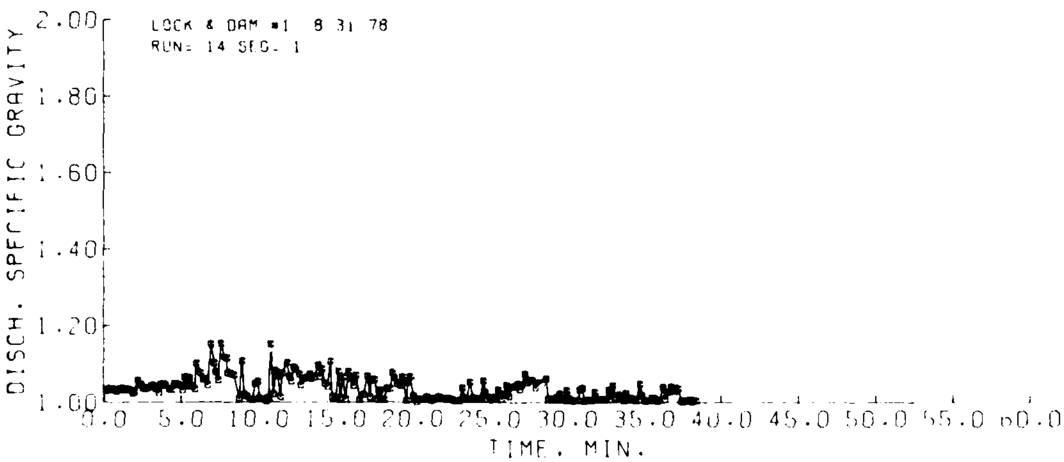
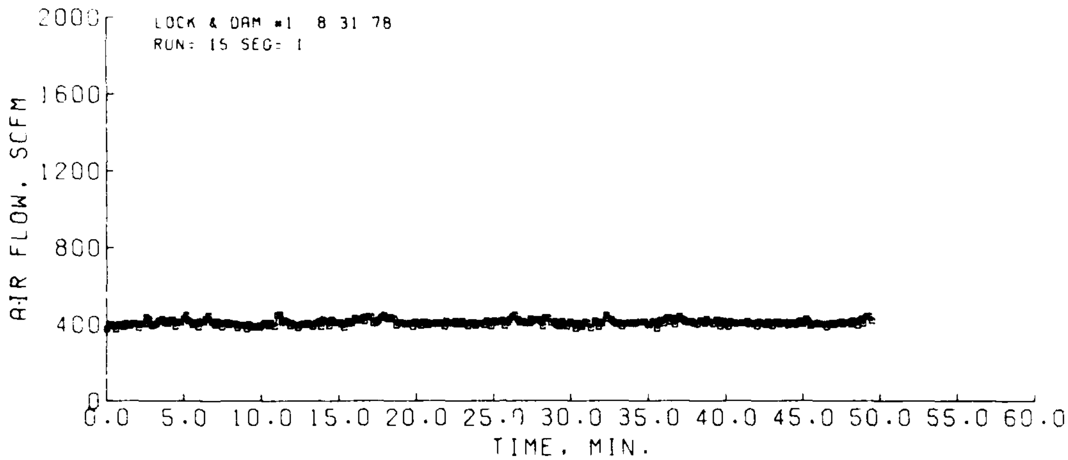
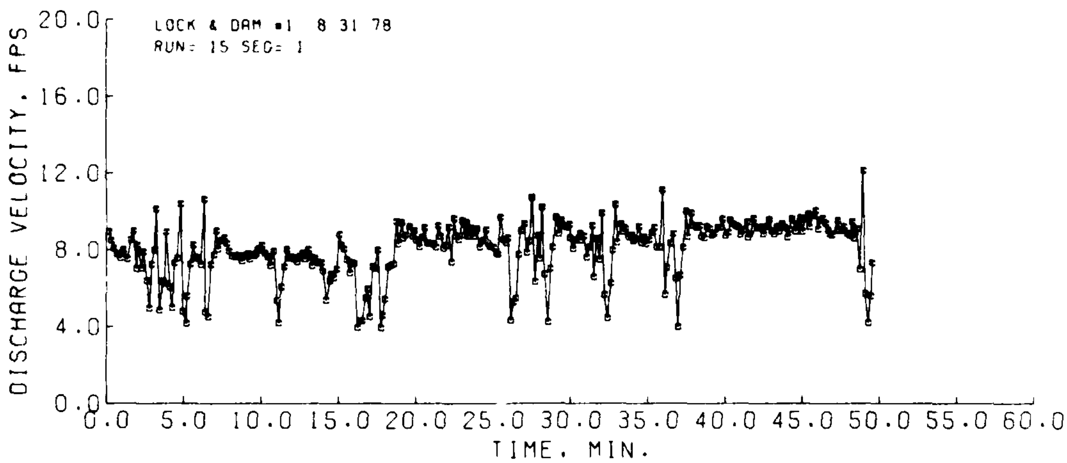

LOCK & DAM #1 8 31 78
RUN: 14 SEG: 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A17


LOCK & DAM #1 8 31 78
RUN= 15 SEG= 1
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


LOCK & DAM #1 8 31 78
RUN= 15 SEG= 1
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

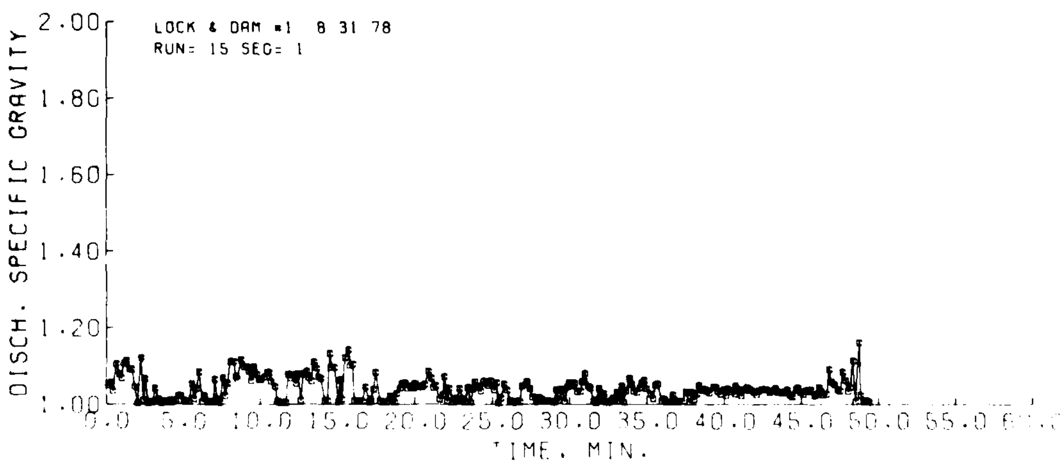

LOCK & DAM #1 8 31 78
RUN= 15 SEG= 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0
TIME, MIN.

PLATE A18

AD-A117 854 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/2
PUMPING PERFORMANCE AND TURBIDITY GENERATION OF MODEL 600/100 P--ETC(U)
APR 82 T W RICHARDSON, J E HITE, R A SHAFER
UNCLASSIFIED WES/TR/HL-82-8-APP-A/B NL

2 OF 2
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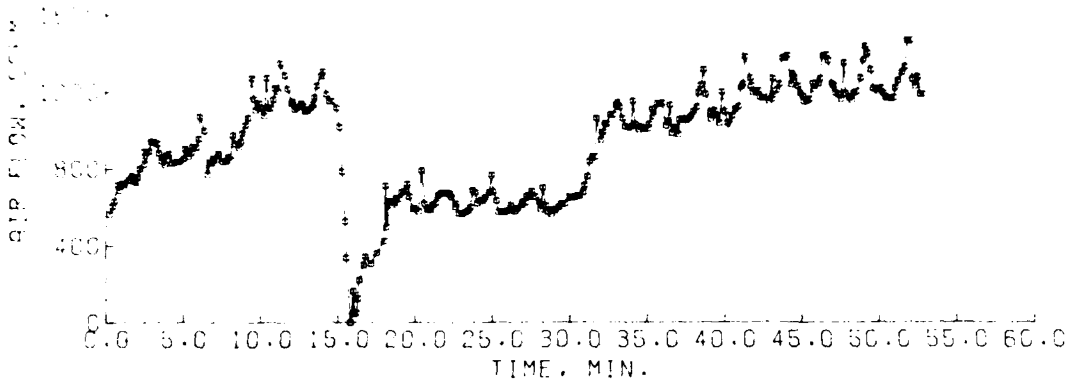
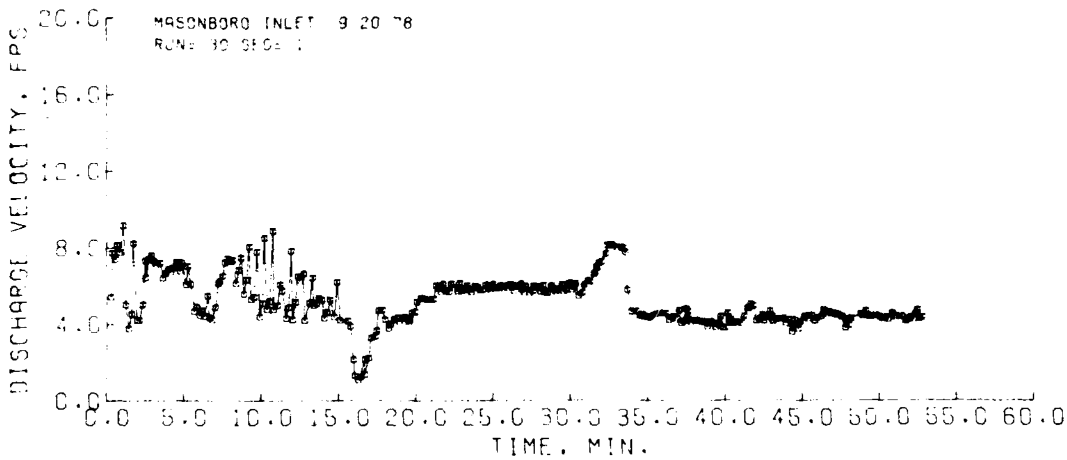
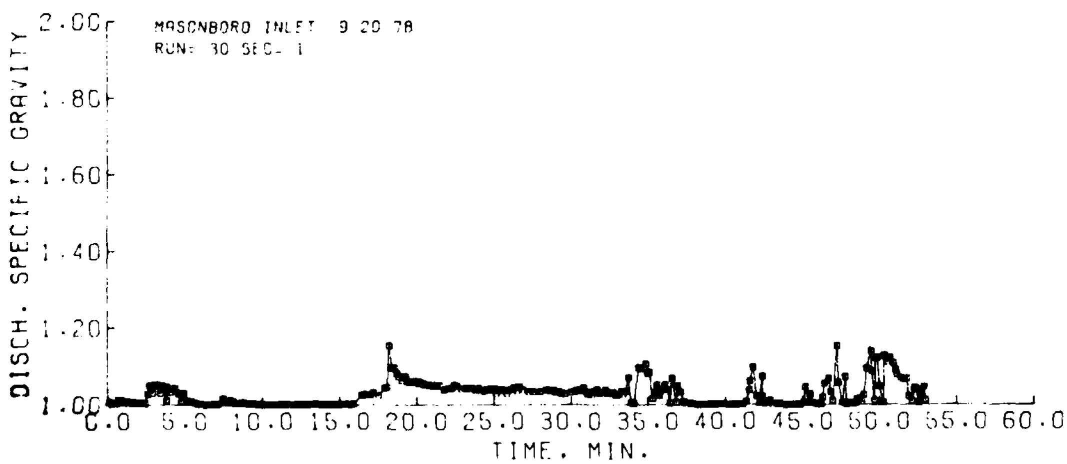


AIR FLOW, CFM
400
800
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

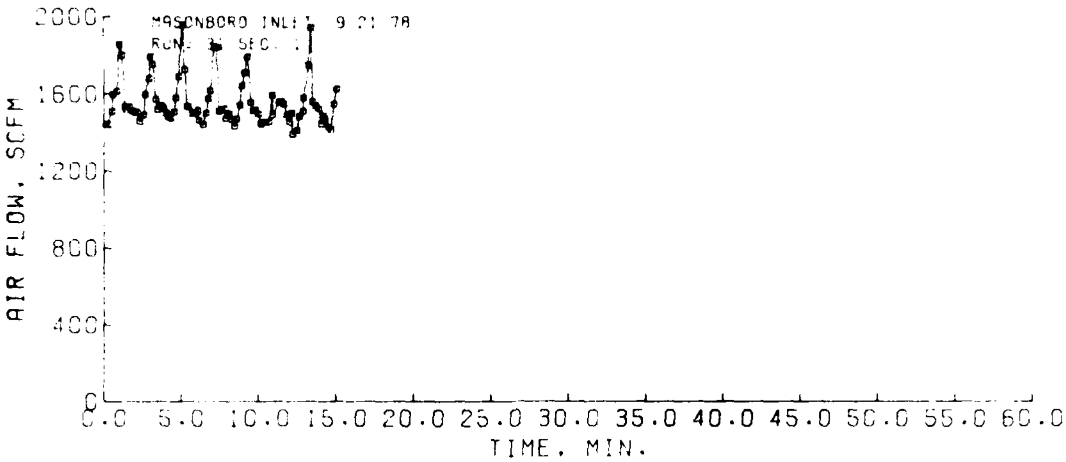


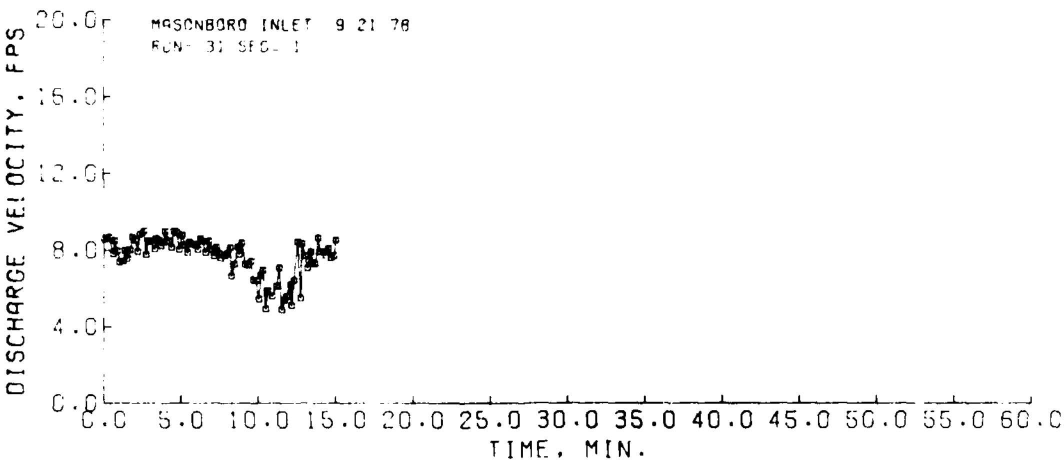
MASONBORO INLET 9 20 78
RUN= 30 SEC= 1
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.



MASONBORO INLET 9 20 78
RUN= 30 SEC= 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A19


MASONBORO INLET 9 21 78
RUN= 31 SEC= 1
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


MASONBORO INLET 9 21 78
RUN= 31 SEC= 1
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

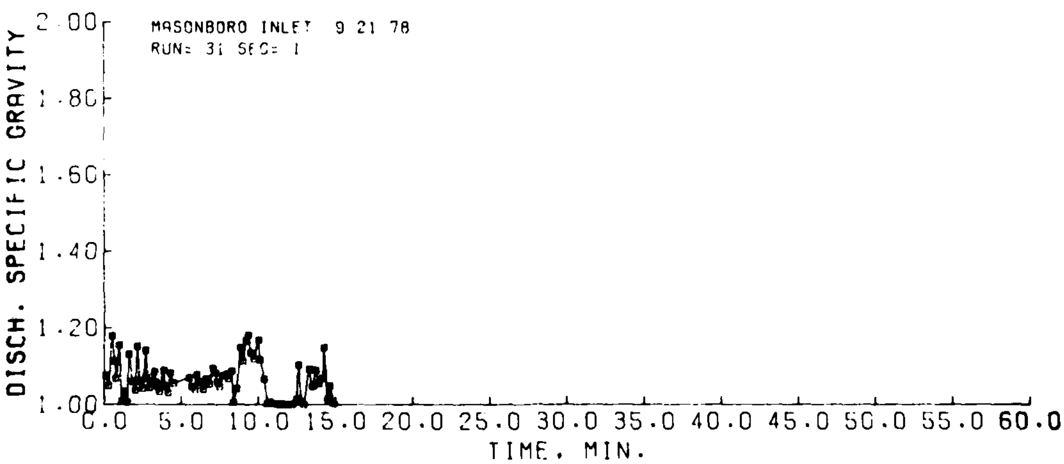
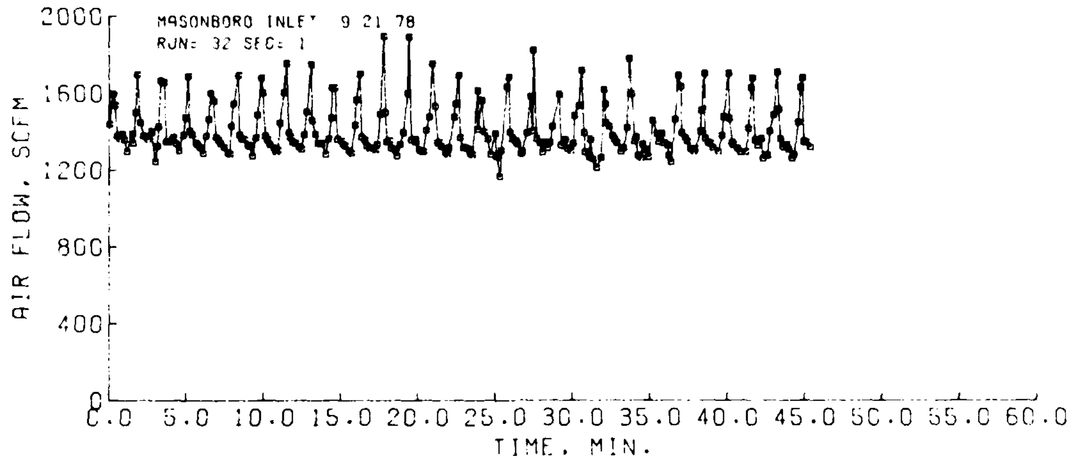
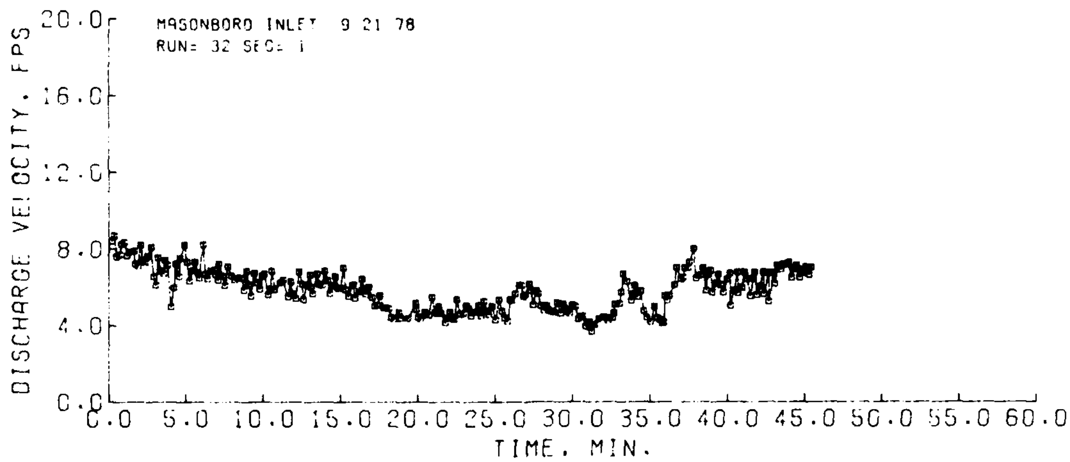

MASONBORO INLET 9 21 78
RUN= 31 SEC= 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A20


MASONBORO INLET 9 21 78
RUN= 32 SEC= 1
AIR FLOW, SCFM
TIME, MIN.


MASONBORO INLET 9 21 78
RUN= 32 SEC= 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

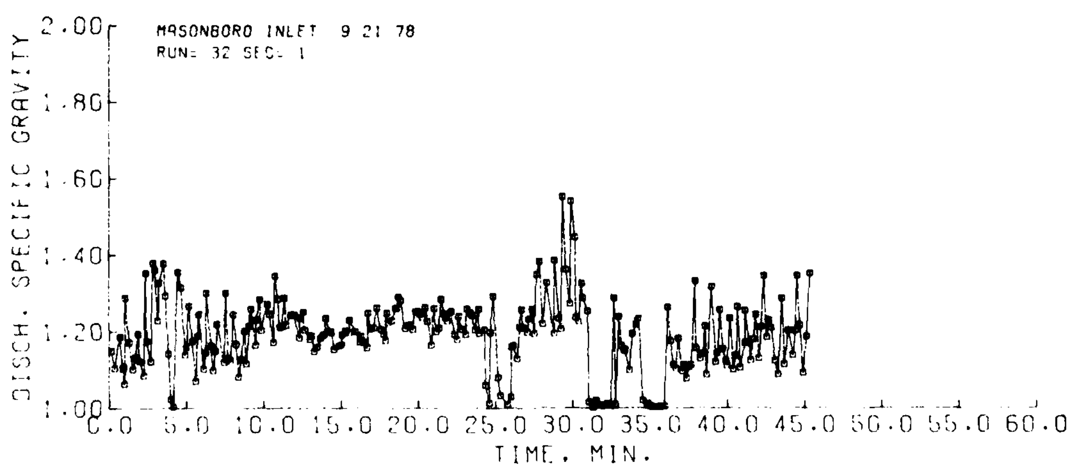
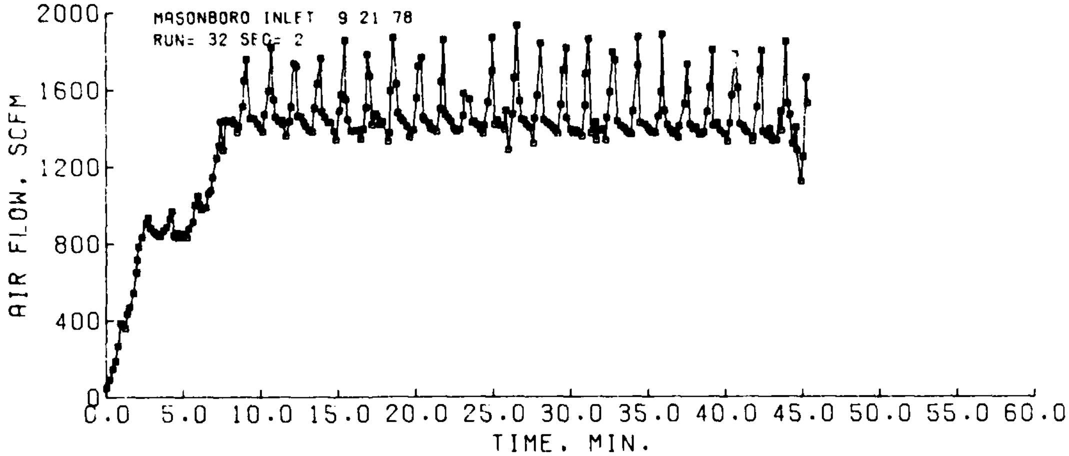
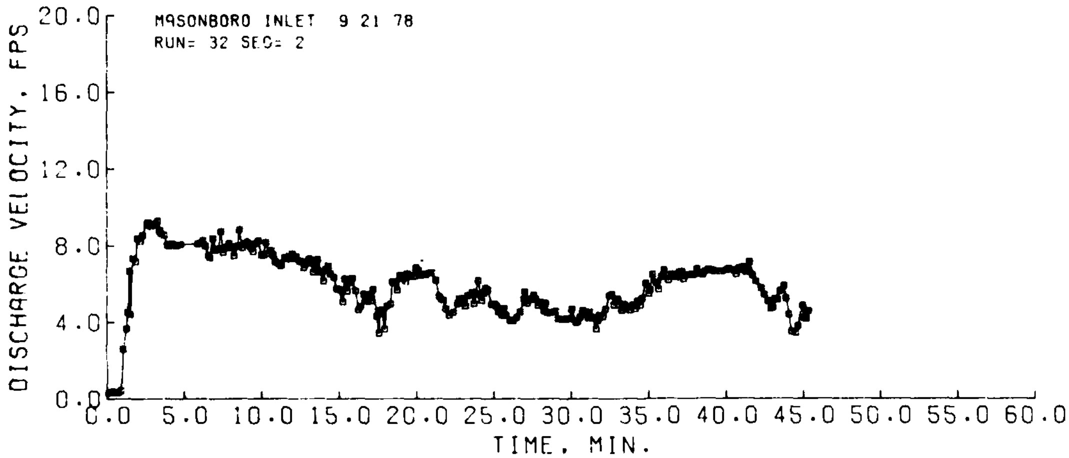

MASONBORO INLET 9 21 78
RUN= 32 SEC= 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A21


MASONBORO INLET 9 21 78
RUN= 32 SEC= 2
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


MASONBORO INLET 9 21 78
RUN= 32 SEC= 2
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

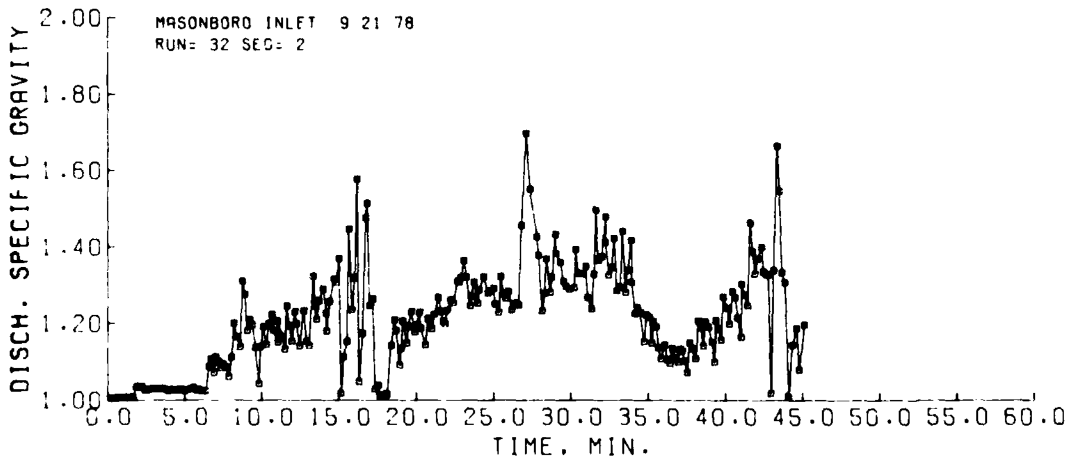
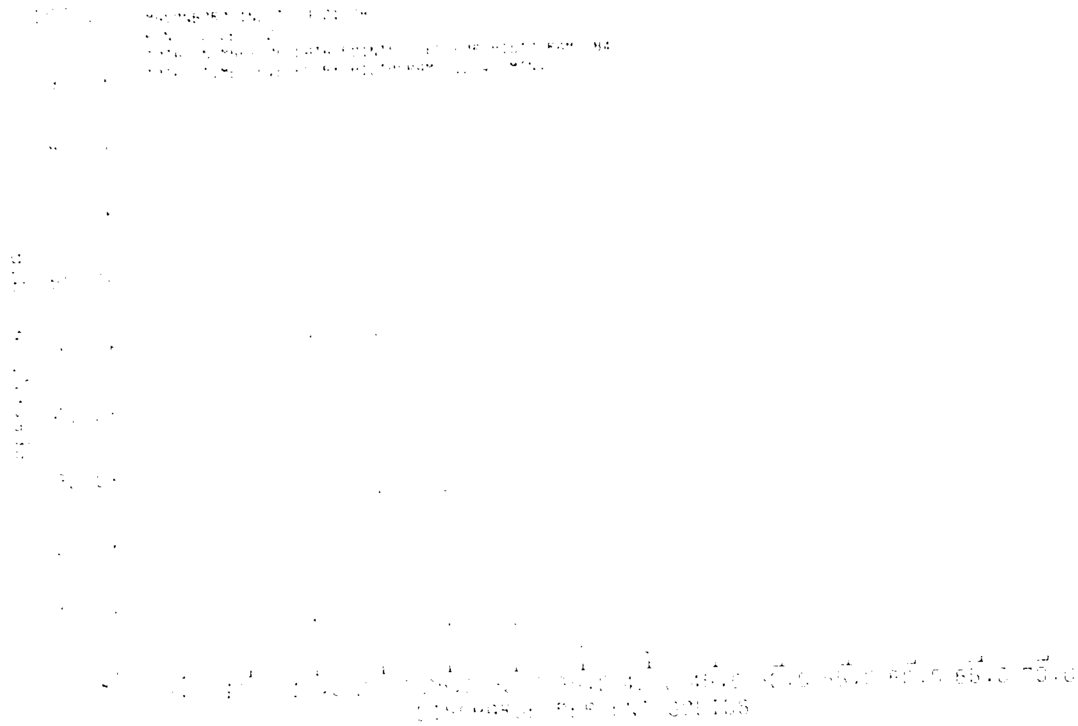

MASONBORO INLET 9 21 78
RUN= 32 SEC= 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A22



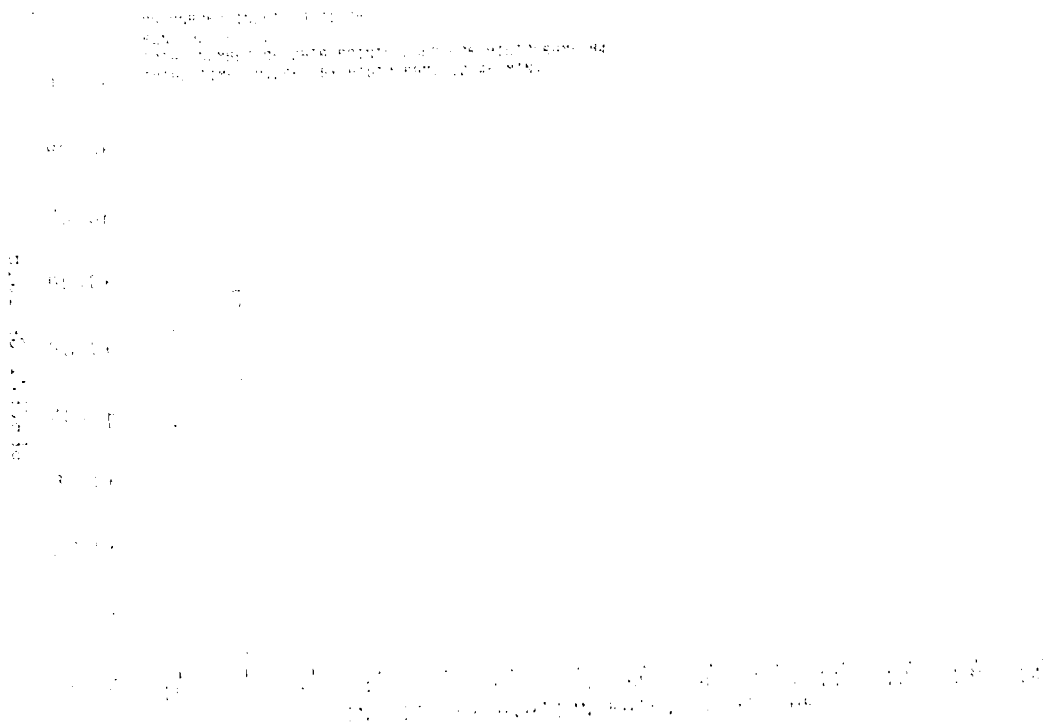
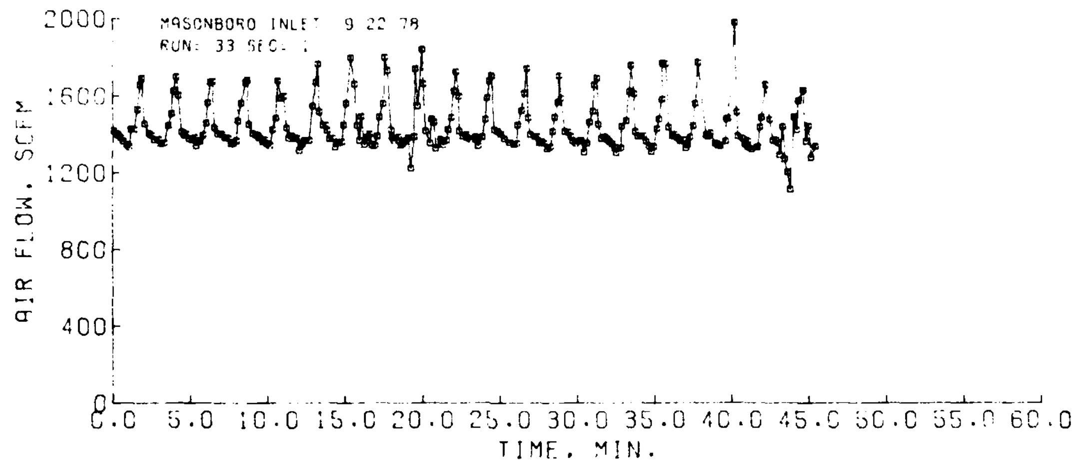
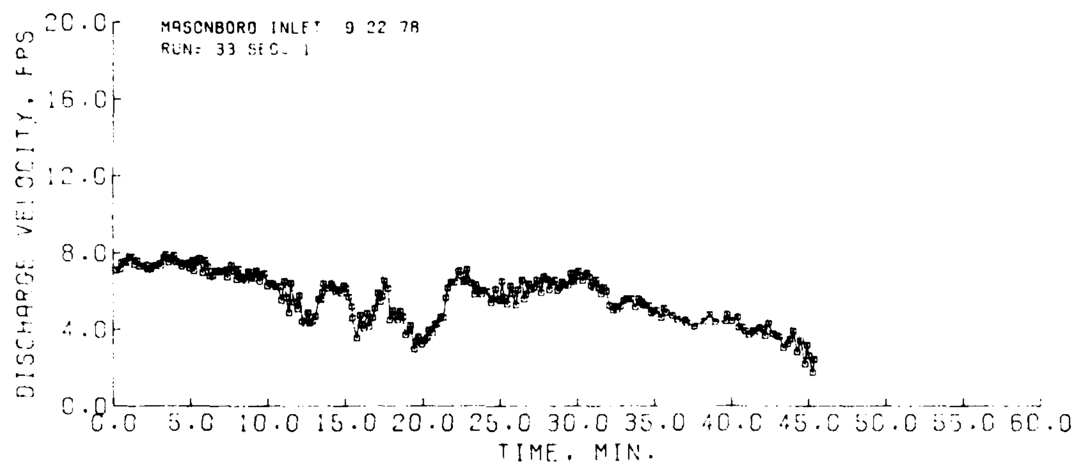


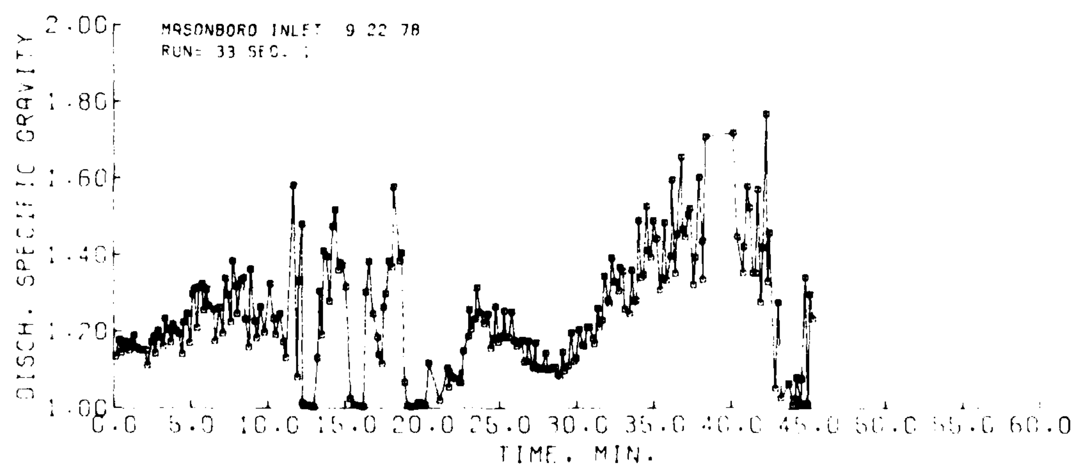
PLATE A23



MASONBORO INLET 9 22 78
RUN: 33 SEC. 1
2000
1600
1200
800
400
0
AIR FLOW, SCFM
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

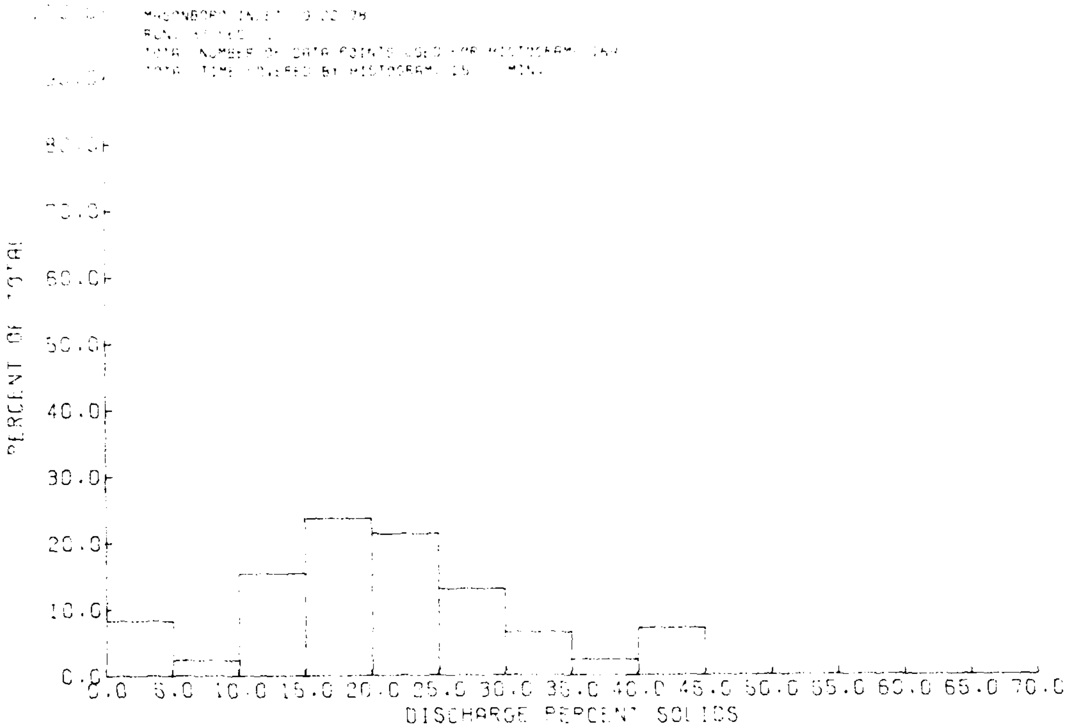


MASONBORO INLET 9 22 78
RUN: 33 SEC. 1
20.0
16.0
12.0
8.0
4.0
0.0
DISCHARGE VELOCITY, FPS
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.



MASONBORO INLET 9 22 78
RUN: 33 SEC. 1
2.00
1.80
1.60
1.40
1.20
1.00
DISCH. SPECIFIC GRAVITY
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A24


PERCENT OF TOTAL
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
DISCHARGE PERCENT SOLIDS

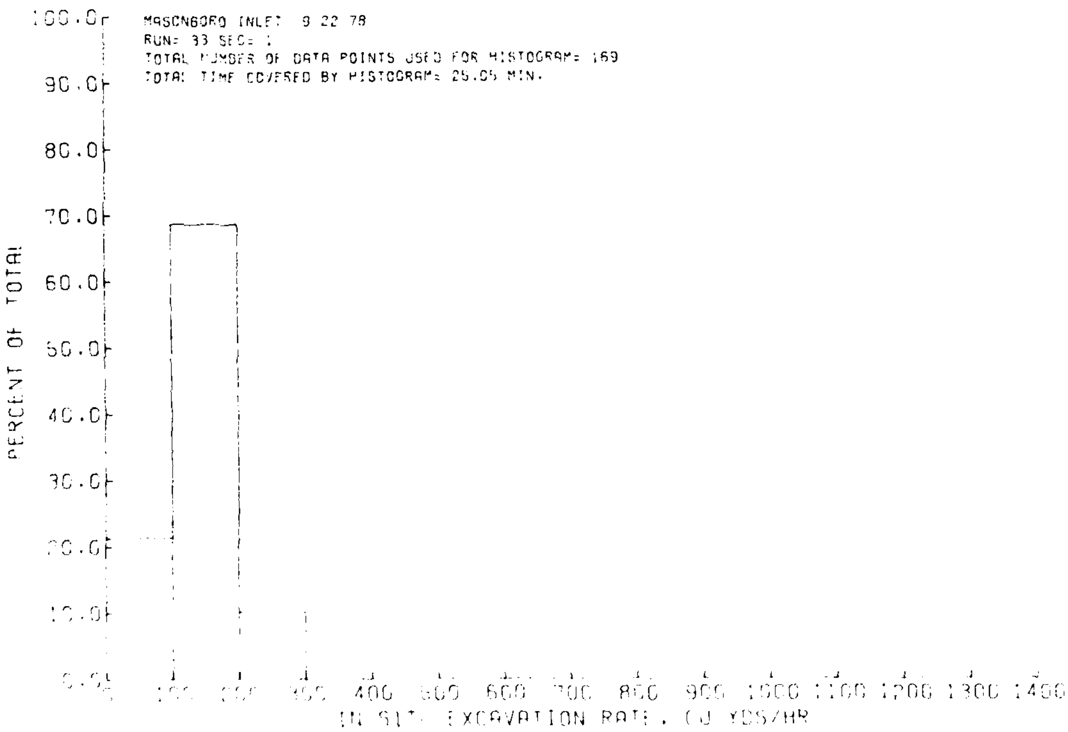
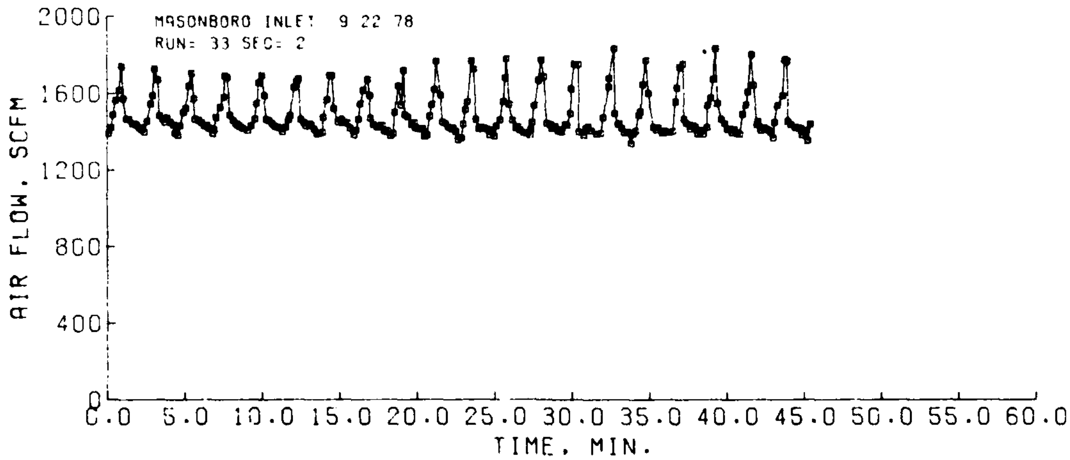
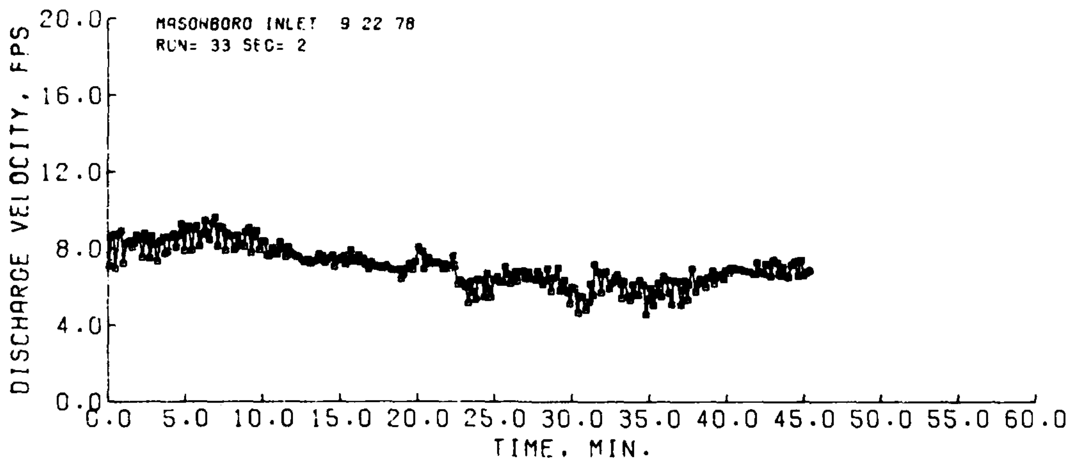

MASONBORO INLET 9 22 78
RUN= 33 SEC= 1
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 169
TOTAL TIME COVERED BY HISTOGRAM= 25.05 MIN.
PERCENT OF TOTAL
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
400 500 600 700 800 900 1000 1100 1200 1300 1400
IN SITU EXCAVATION RATE, CU YDS/HR

PLATE A25


MASONBORO INLET 9 22 78
RUN= 33 SEC= 2
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


MASONBORO INLET 9 22 78
RUN= 33 SEC= 2
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

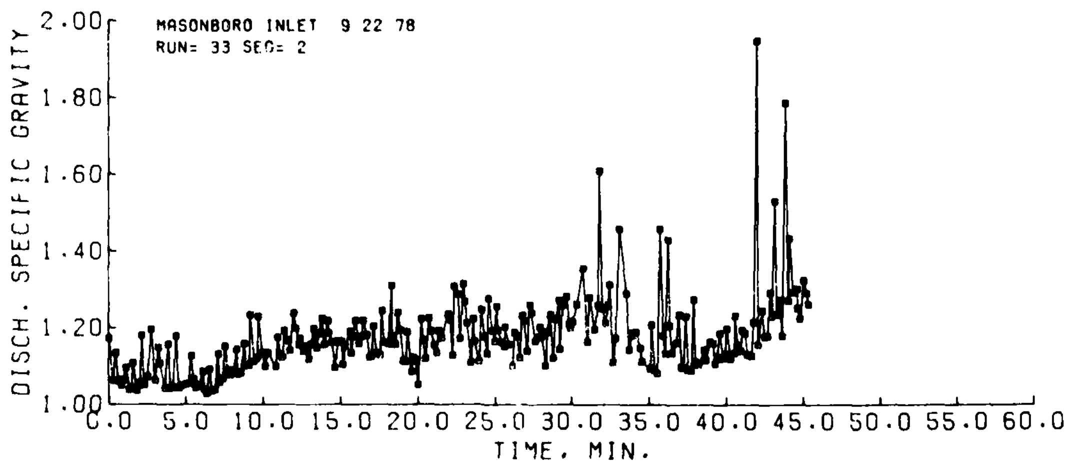
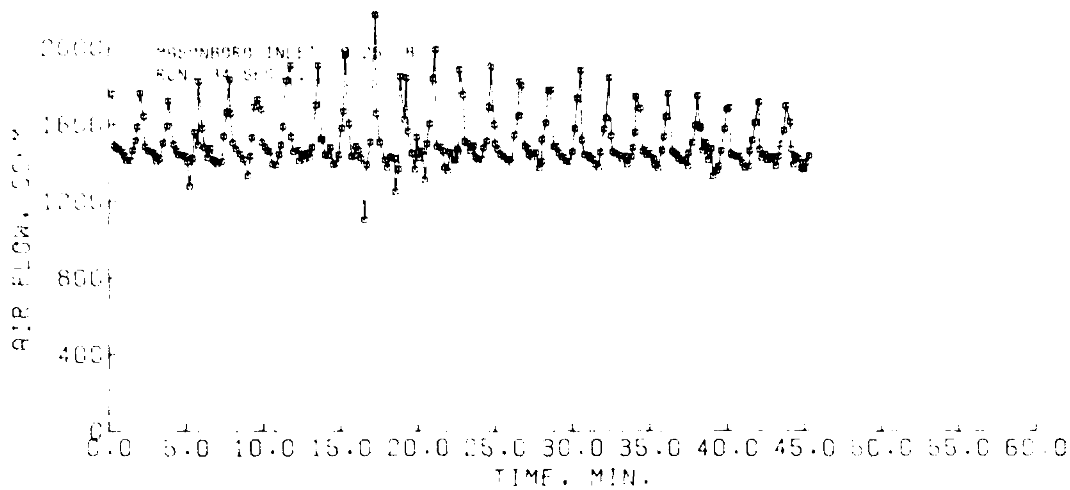
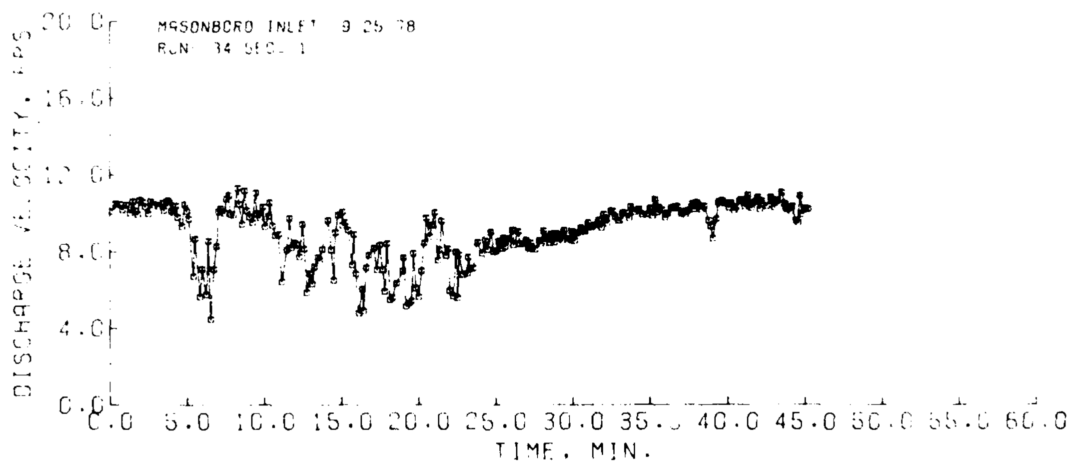

MASONBORO INLET 9 22 78
RUN= 33 SEC= 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A26


MASONBORO INLET
RUN 34
AIR FLOW, SCFM
TIME, MIN.


MASONBORO INLET 9 25 78
RUN 34 SEQ. 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

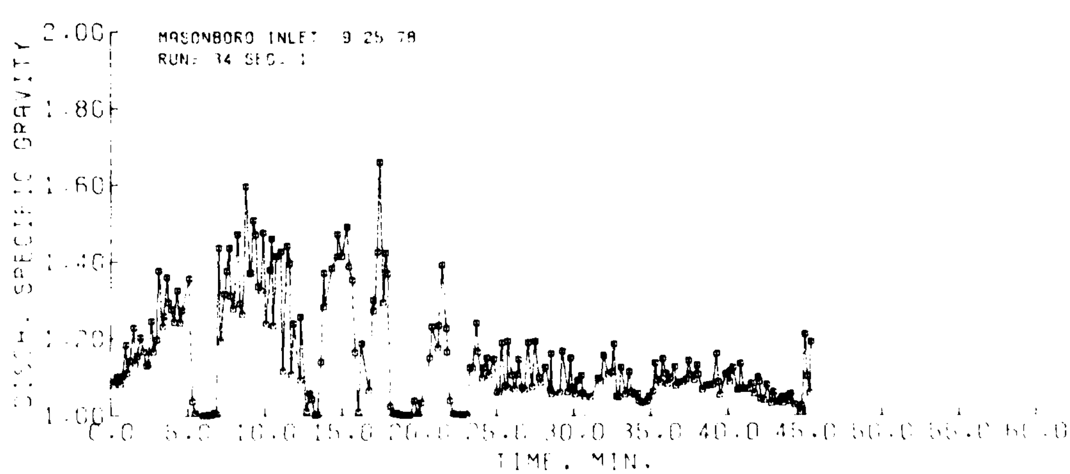
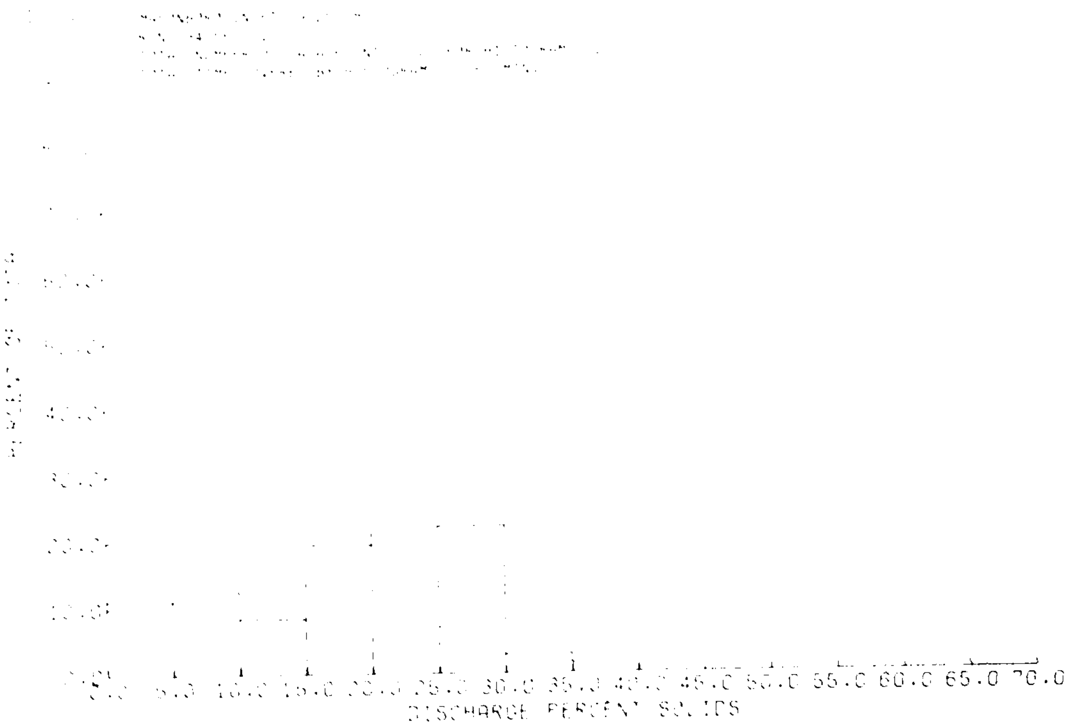

MASONBORO INLET 9 25 78
RUN 34 SEQ. 1
SPECIFIC GRAVITY
TIME, MIN.

PLATE A27


35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
DISCHARGE PERCENT SOLIDS

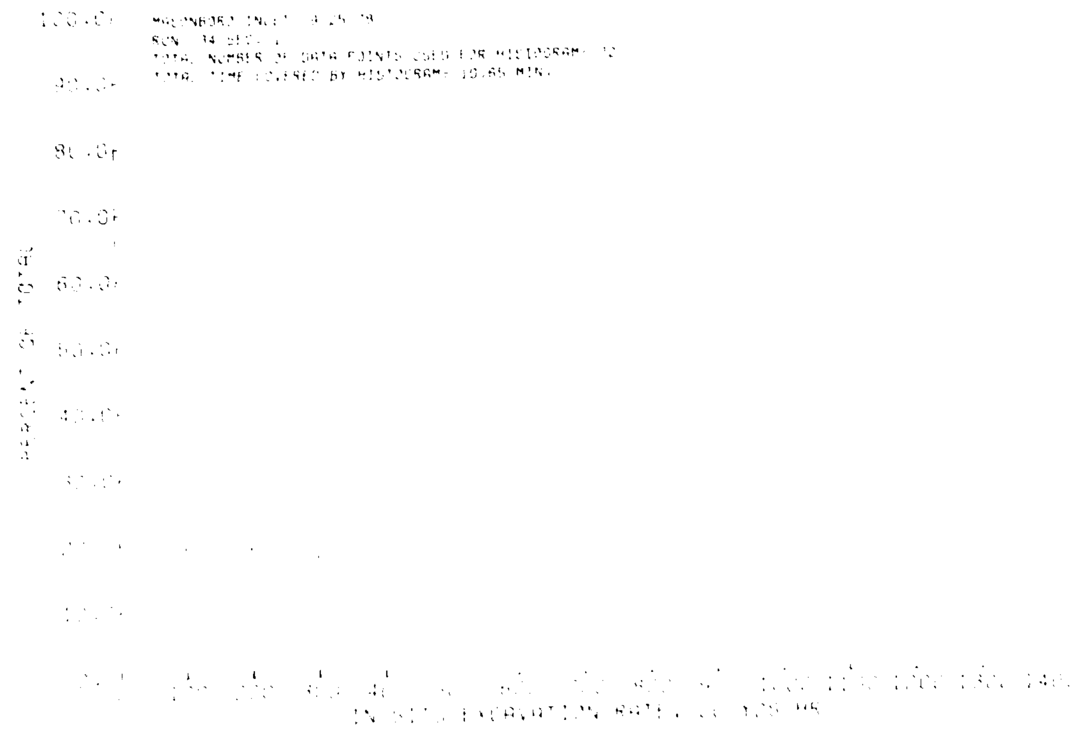
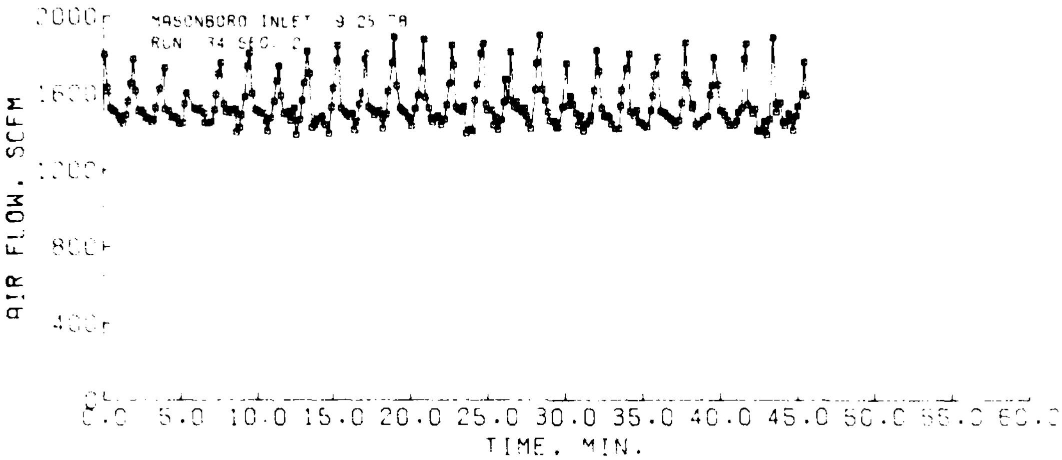
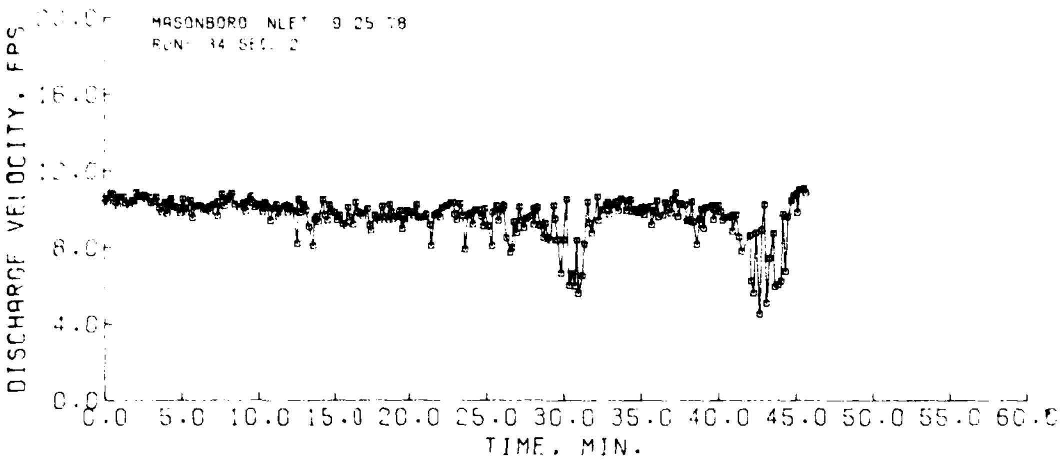

100.0
80.0
70.0
TOTAL TIME COVERED BY HISTOGRAM 10.65 MIN.

PLATE A28


MASONBORO INLET 9 25 78
RUN 34 SEC. 2
AIR FLOW, SCFM
TIME, MIN.


MASONBORO INLET 9 25 78
RUN 34 SEC. 2
DISCHARGE VELOCITY, FPS
TIME, MIN.

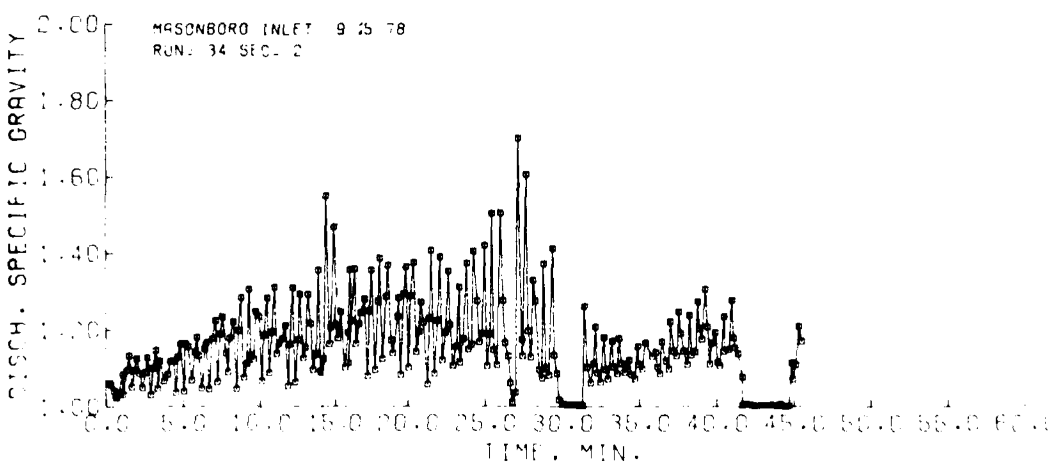
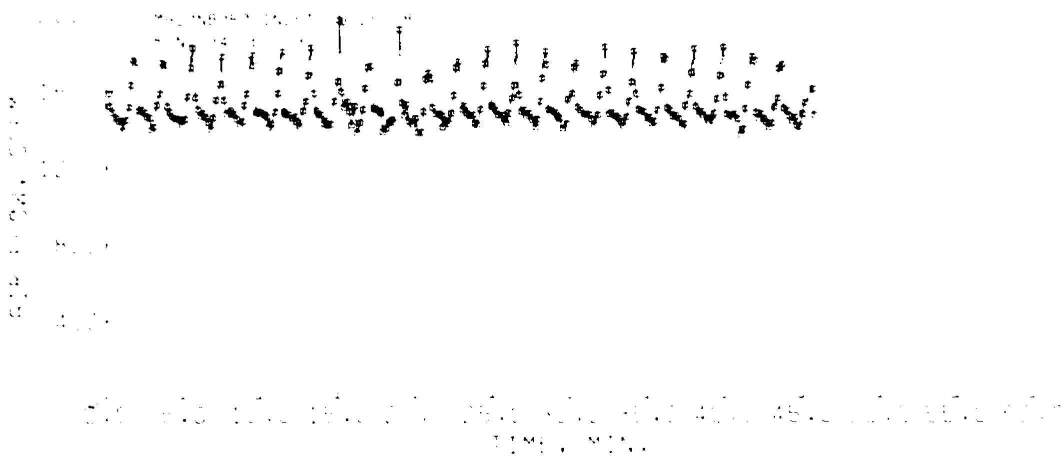
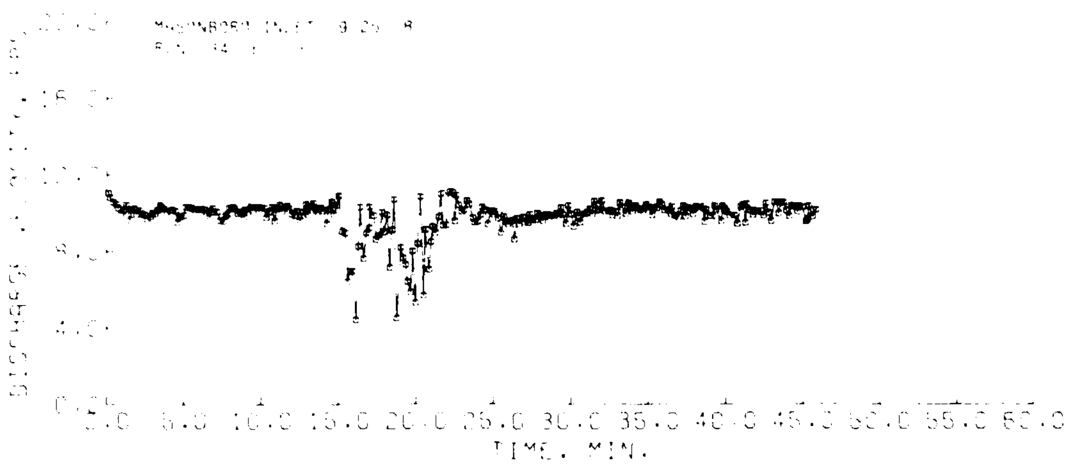

MASONBORO INLET 9 25 78
RUN 34 SEC. 2
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A29




MASONBORO INLET 9.25.78
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

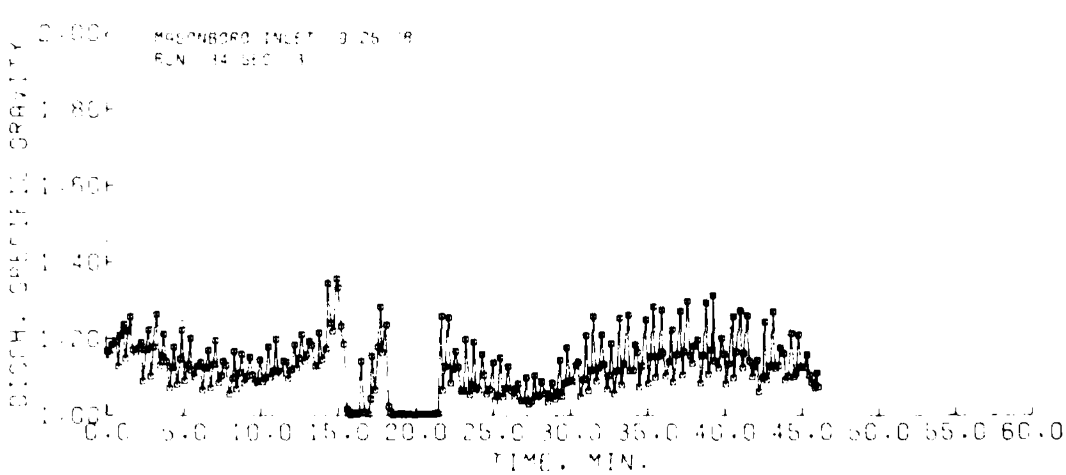
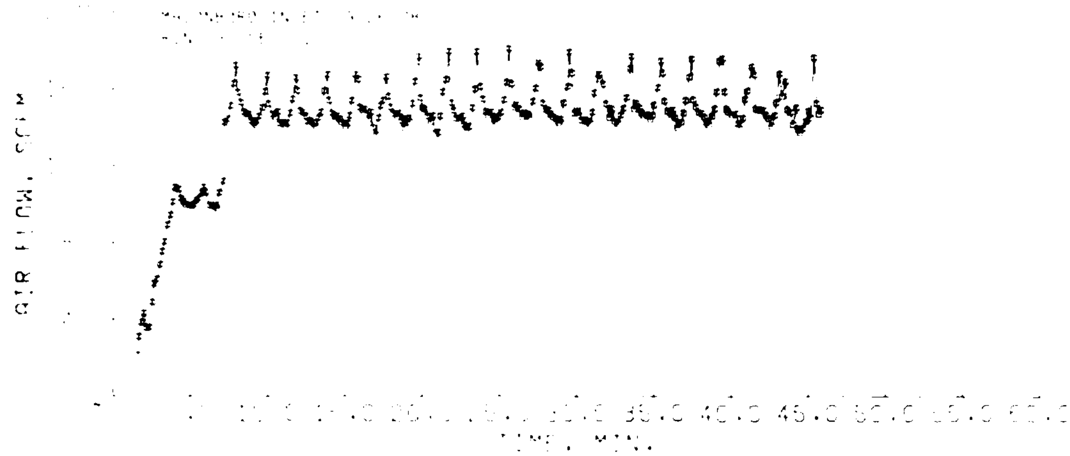
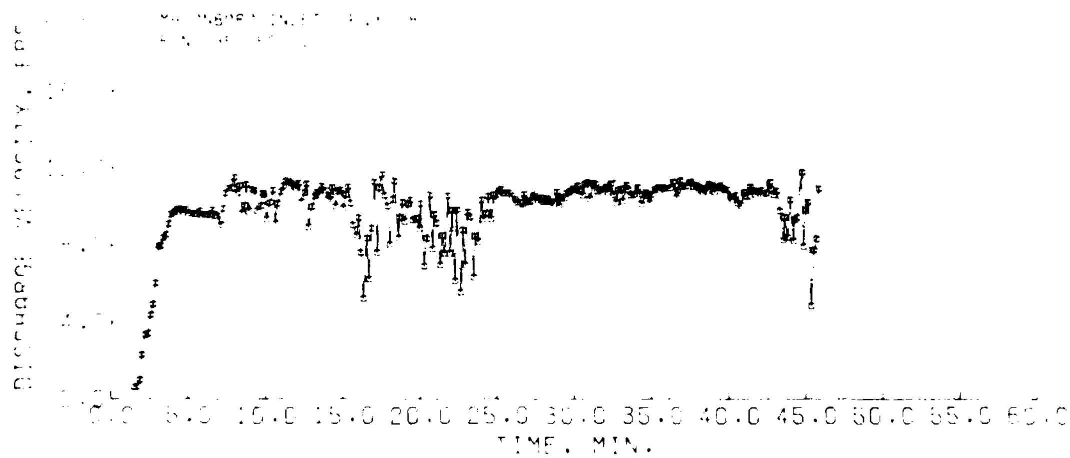

MASONBORO INLET 9.25.78
RUN 34 SEC 3
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A30


AIR FLOW, SCFM
TIME, MIN.


0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

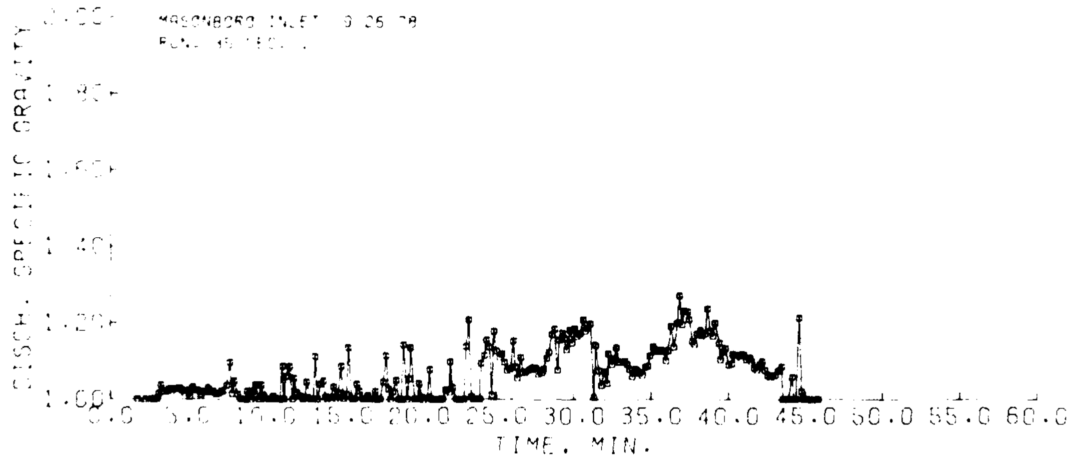
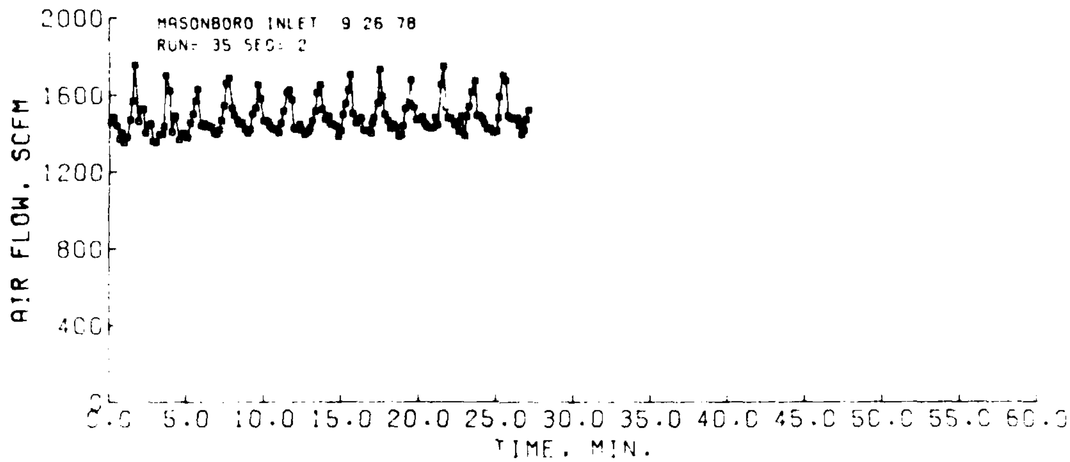
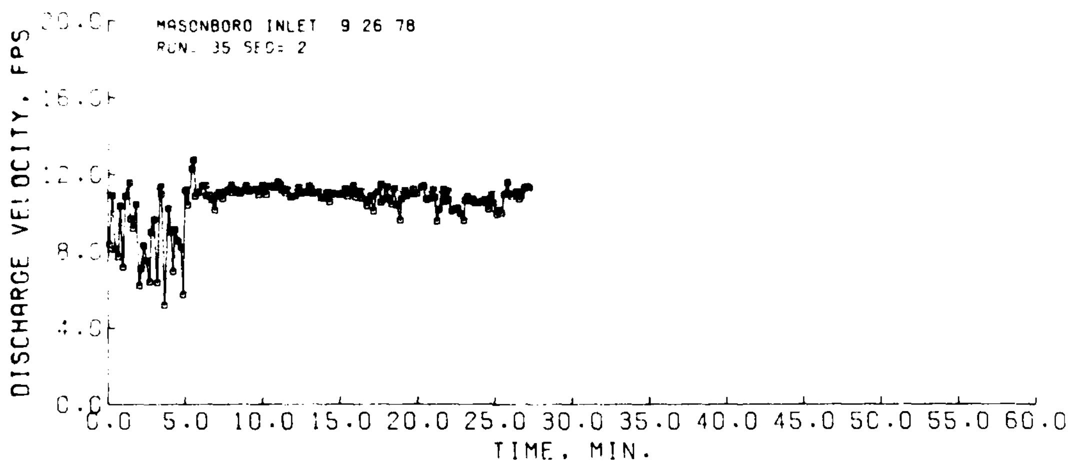

MASONBORO INLET
DISCH. SPECIFIC GRAVITY
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A31


MASONBORO INLET 9 26 78
RUN= 35 SEC= 2
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


MASONBORO INLET 9 26 78
RUN= 35 SEC= 2
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

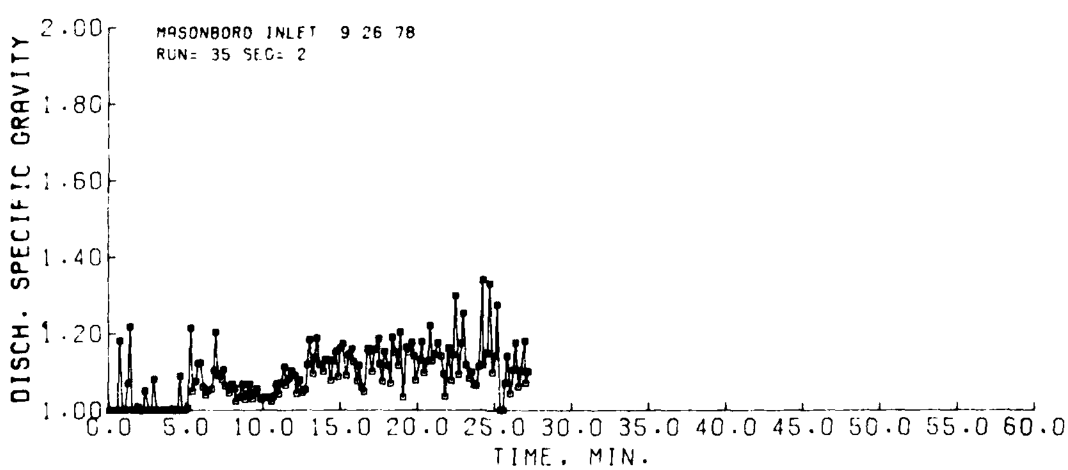
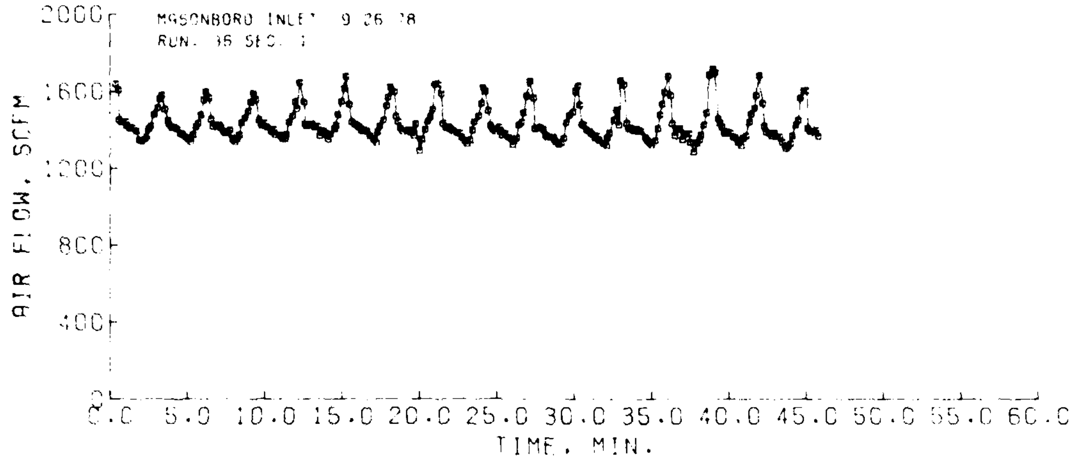
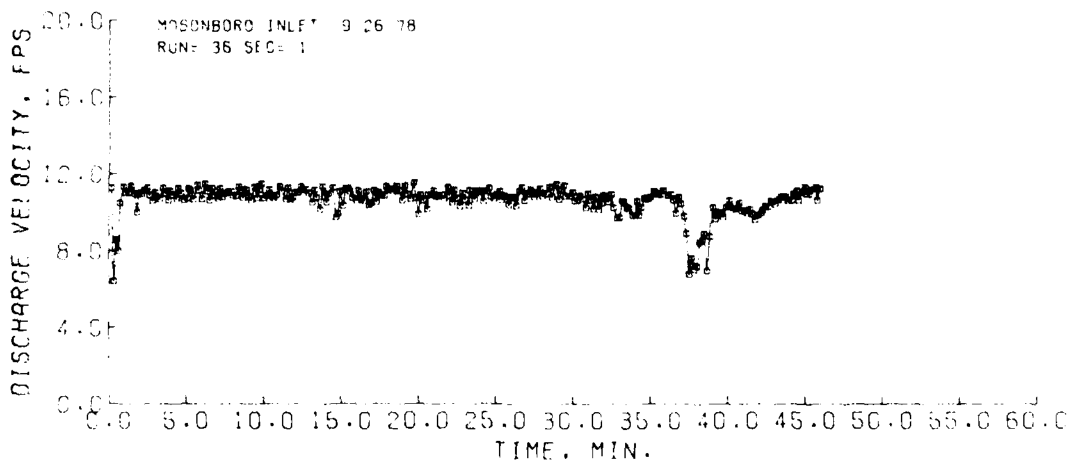

MASONBORO INLET 9 26 78
RUN= 35 SEC= 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

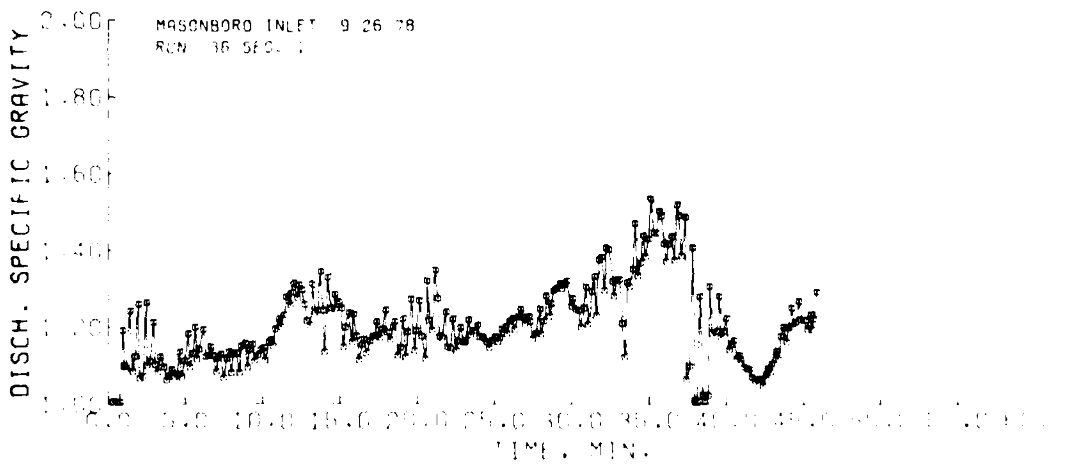
PLATE A32



MASONBORO INLET 9 26 78
RUN: 36 SEC: 1
AIR FLOW, SCFM
TIME, MIN.

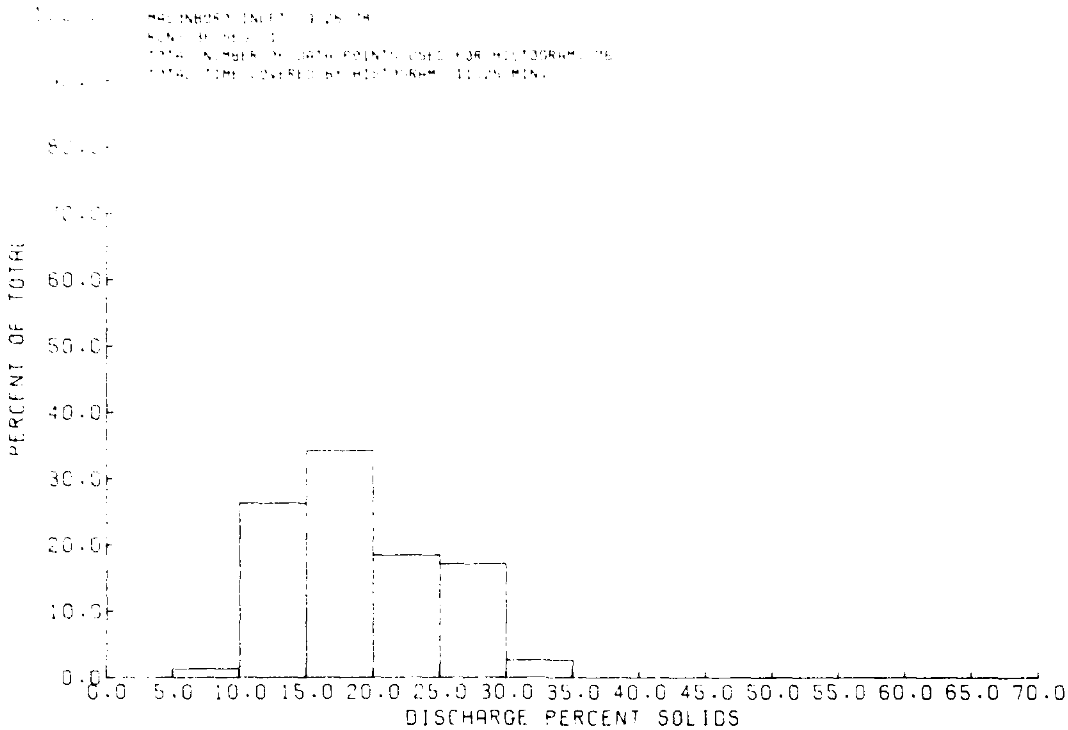


MASONBORO INLET 9 26 78
RUN: 36 SEC: 1
DISCHARGE VELOCITY, FPS
TIME, MIN.



MASONBORO INLET 9 26 78
RUN: 36 SEC: 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A33


PERCENT OF TOTAL
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
DISCHARGE PERCENT SOLIDS

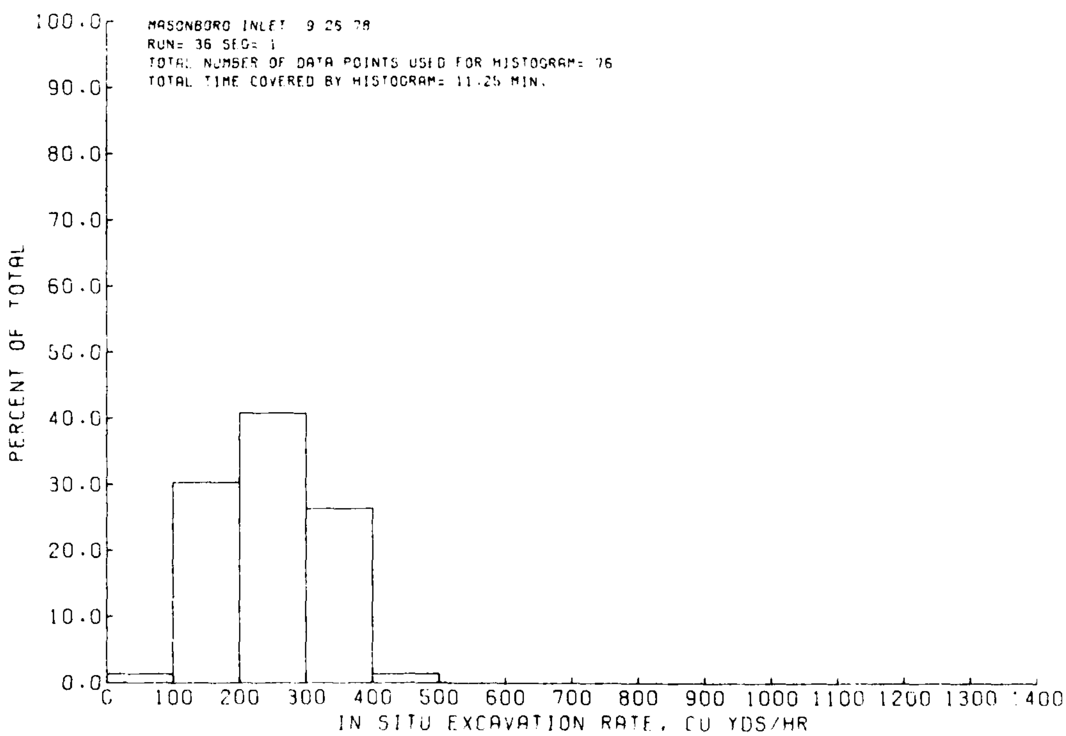
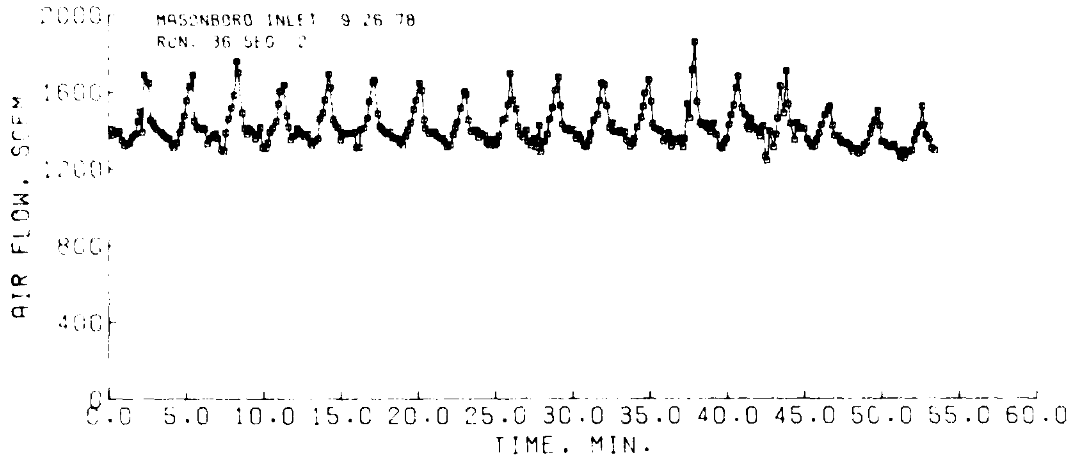
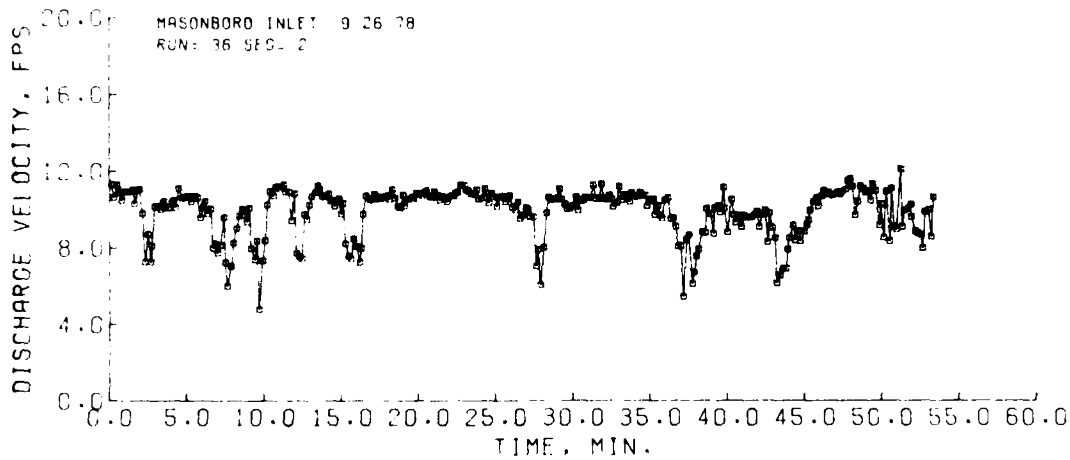

MASONBORO INLET 9 25 78
RUN= 36 SEG= 1
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 76
TOTAL TIME COVERED BY HISTOGRAM= 11.25 MIN.
PERCENT OF TOTAL
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
IN SITU EXCAVATION RATE, CU YDS/HR

PLATE A34


MASONBORO INLET 9 26 78
RUN: 36 SEG: 2
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


MASONBORO INLET 9 26 78
RUN: 36 SEG: 2
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

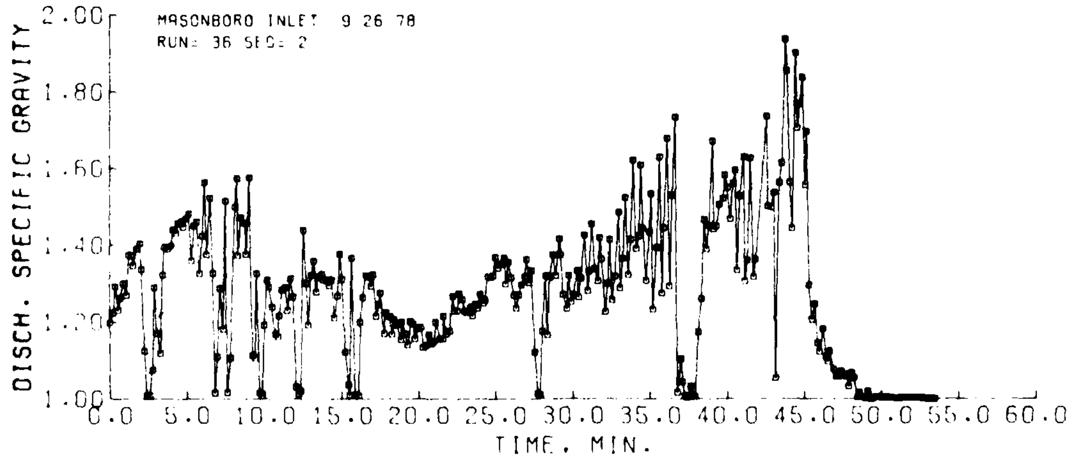
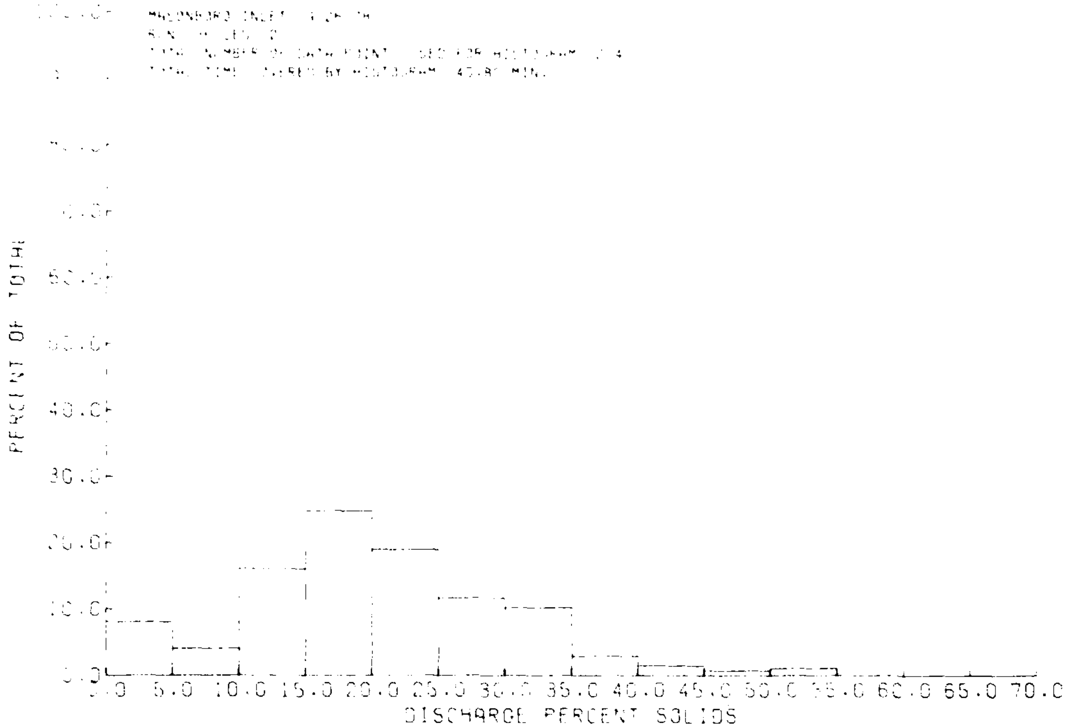
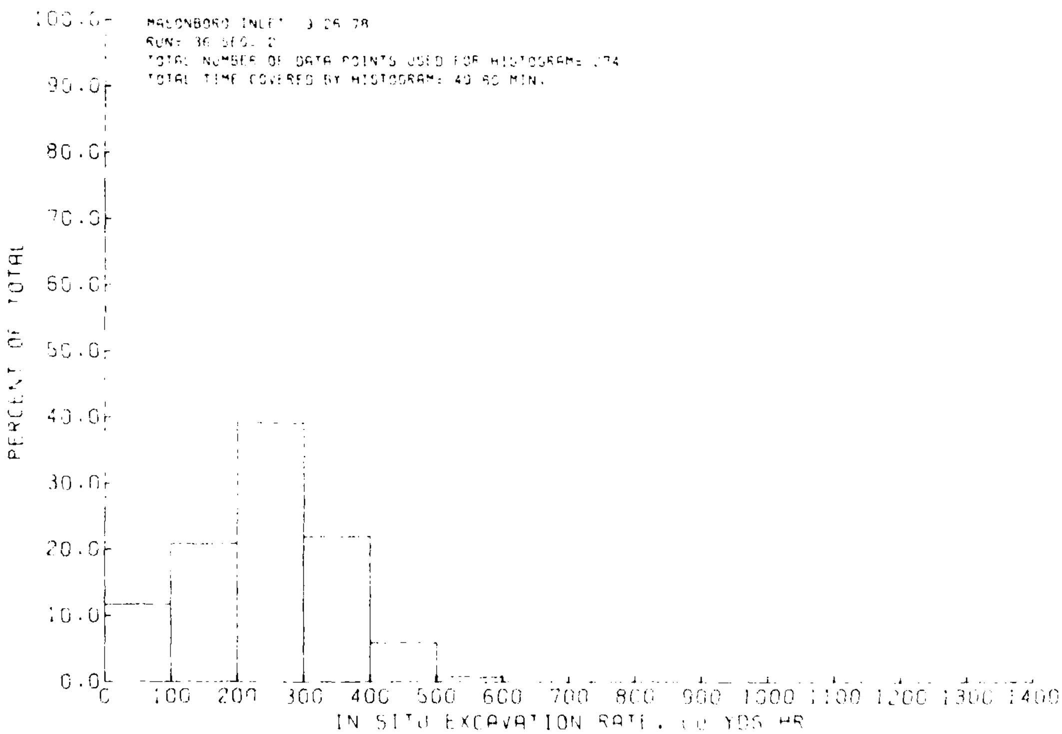

MASONBORO INLET 9 26 78
RUN: 36 SEG: 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A35

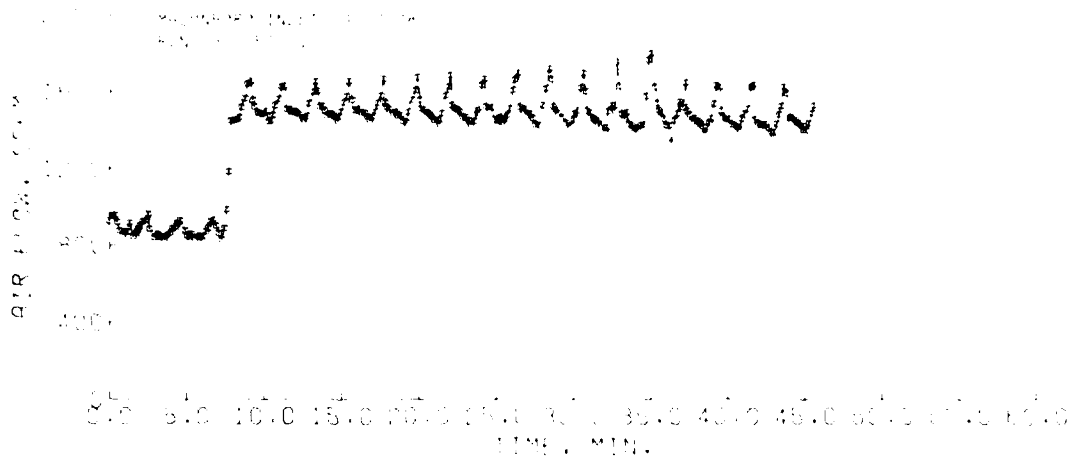


PERCENT OF TOTAL
DISCHARGE PERCENT SOLIDS

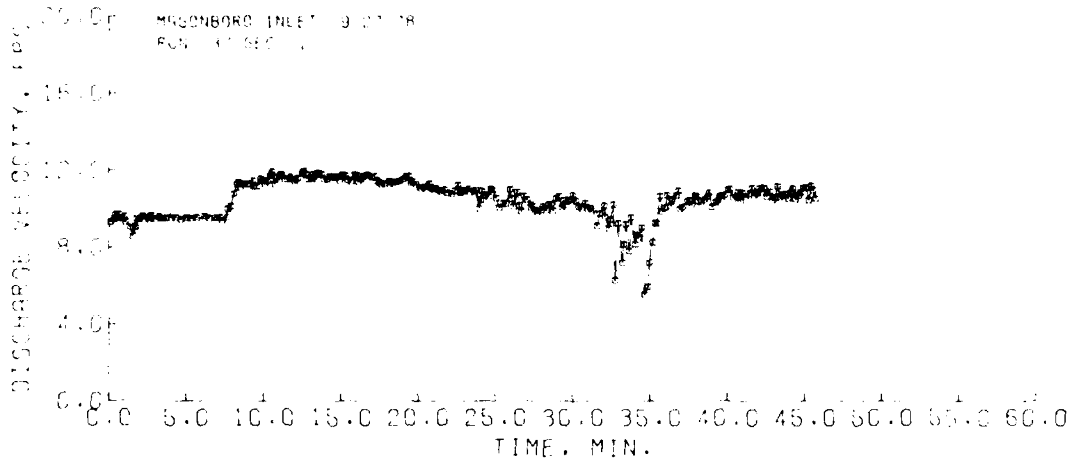


MASONBORO INLET 3 26 78
RUN: 36 SEG. 2
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM: 274
TOTAL TIME COVERED BY HISTOGRAM: 40.80 MIN.
PERCENT OF TOTAL
IN SITU EXCAVATION RATE, CU YDS HR

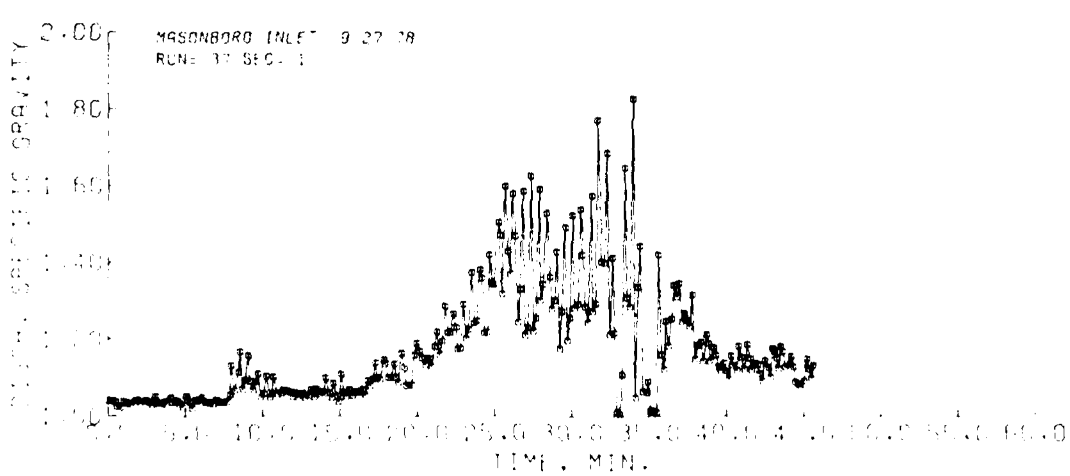
PLATE A36



TIME, MIN.

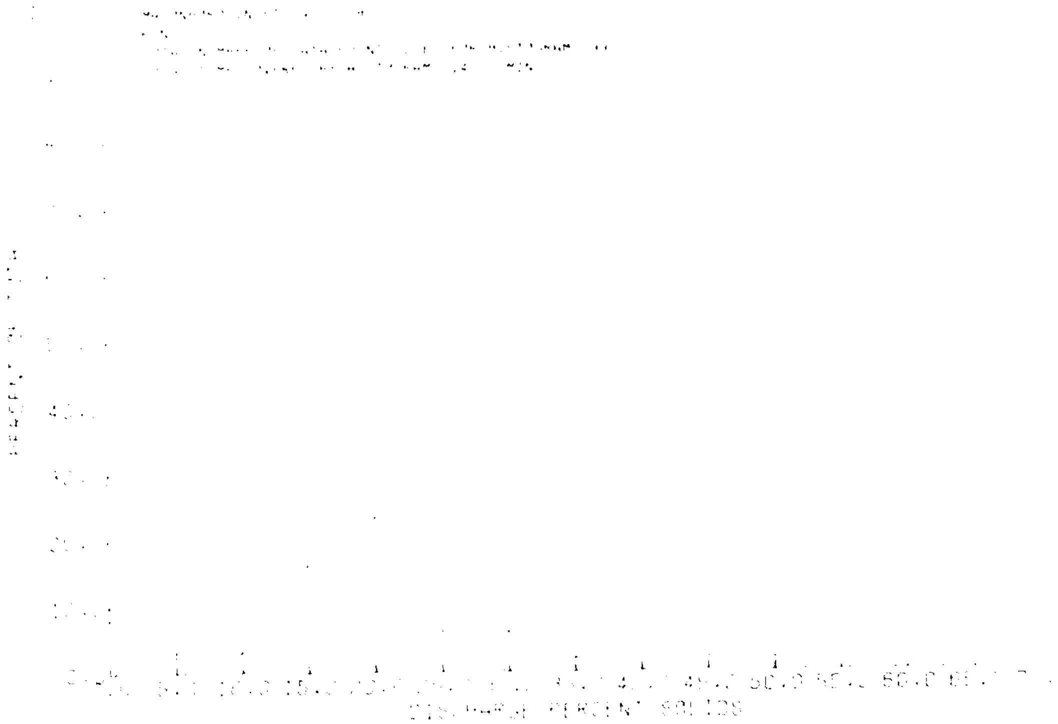


MASONBORO INLET
DISCHARGE VELOCITY
16.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 60.0
TIME, MIN.



MASONBORO INLET 9 27 78
2.00
1.80
1.60
TIME, MIN.

PLATE A37



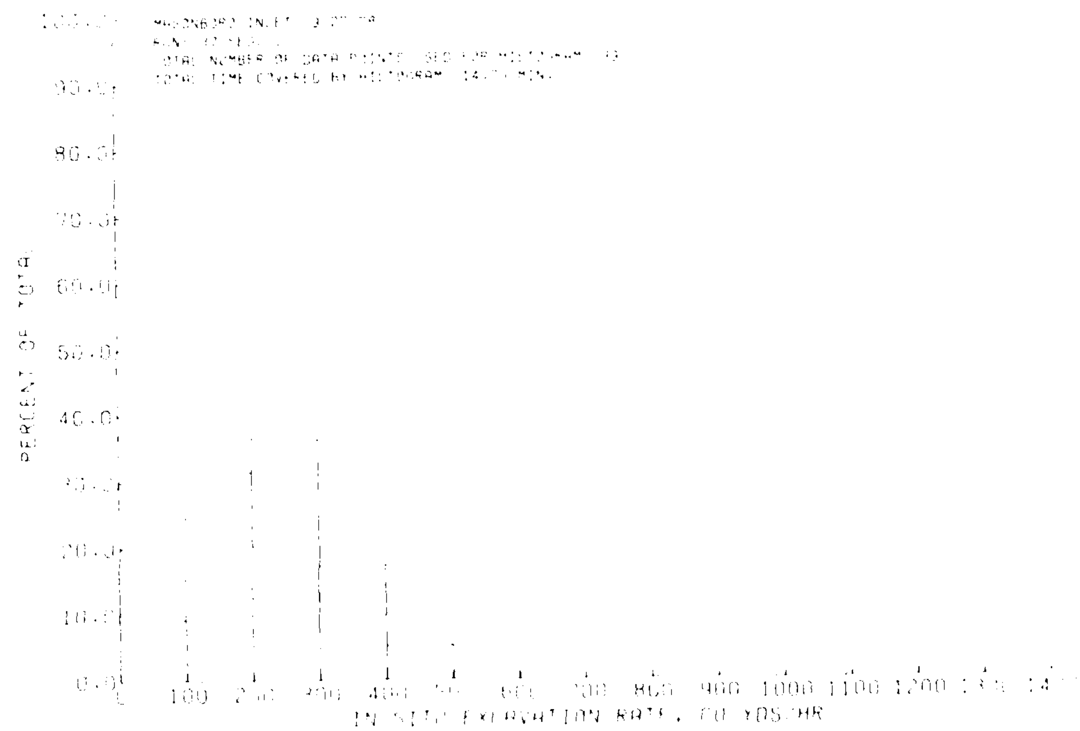
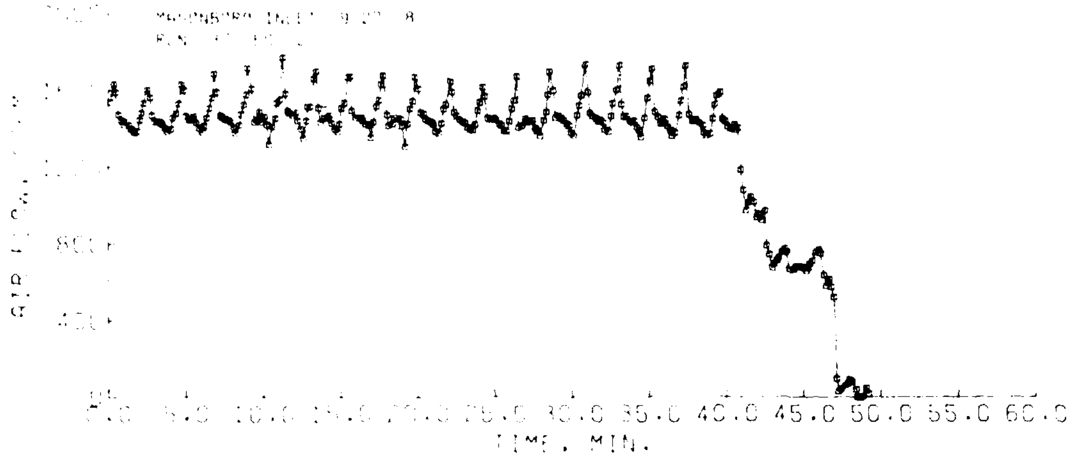
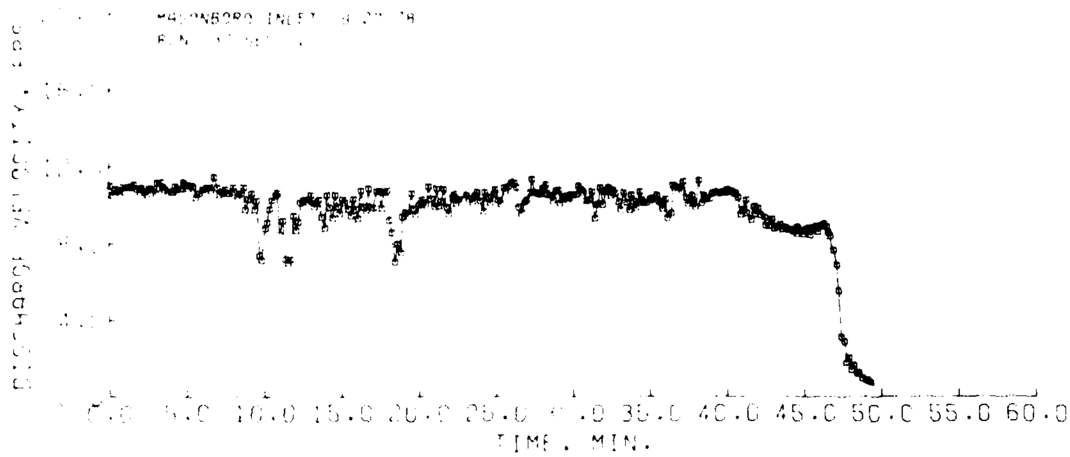


PLATE A38





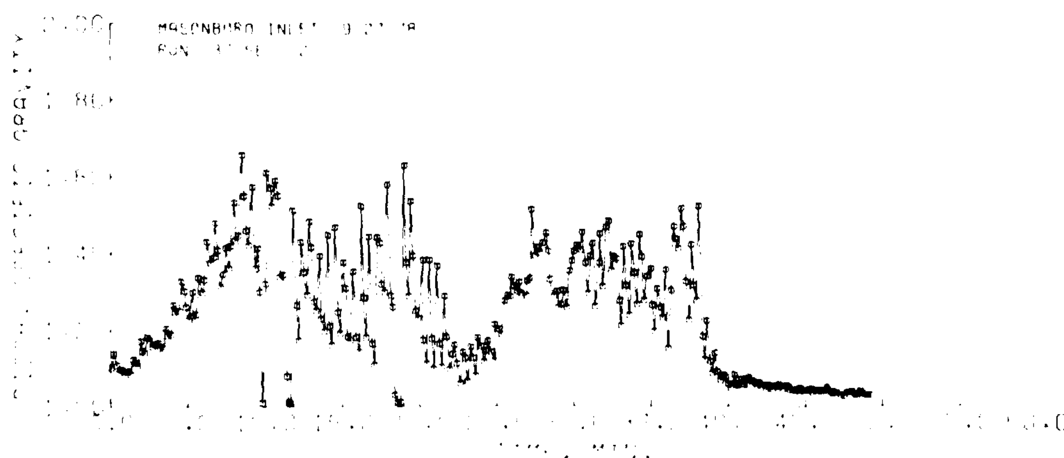
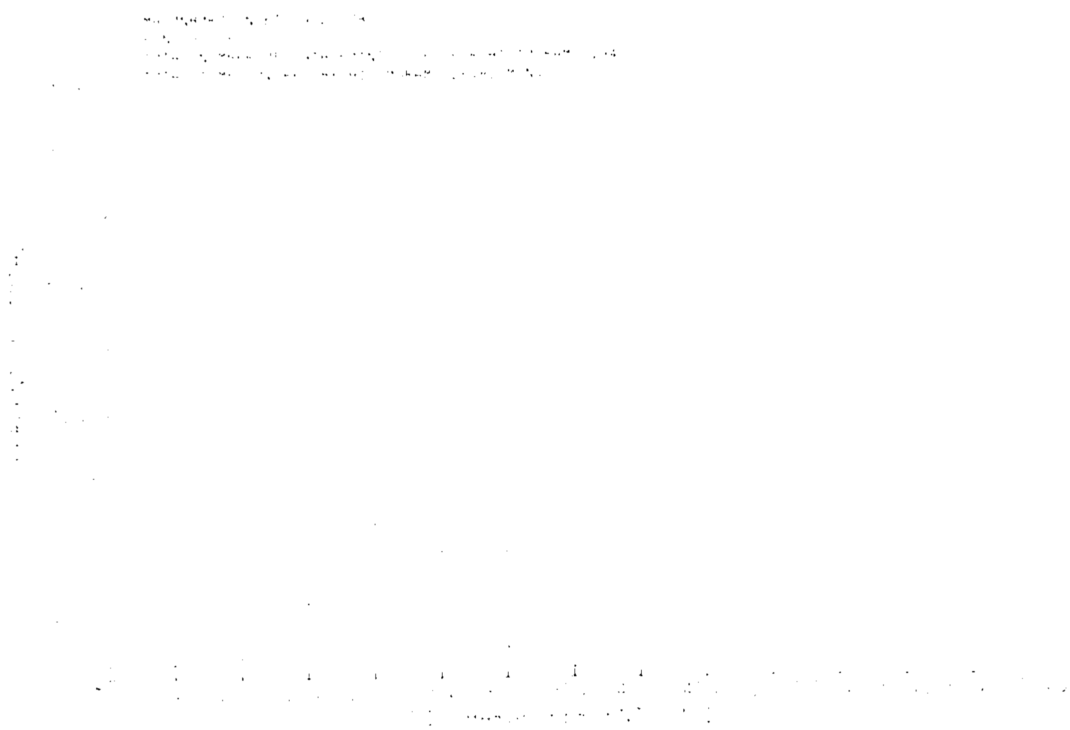


PLATE A39



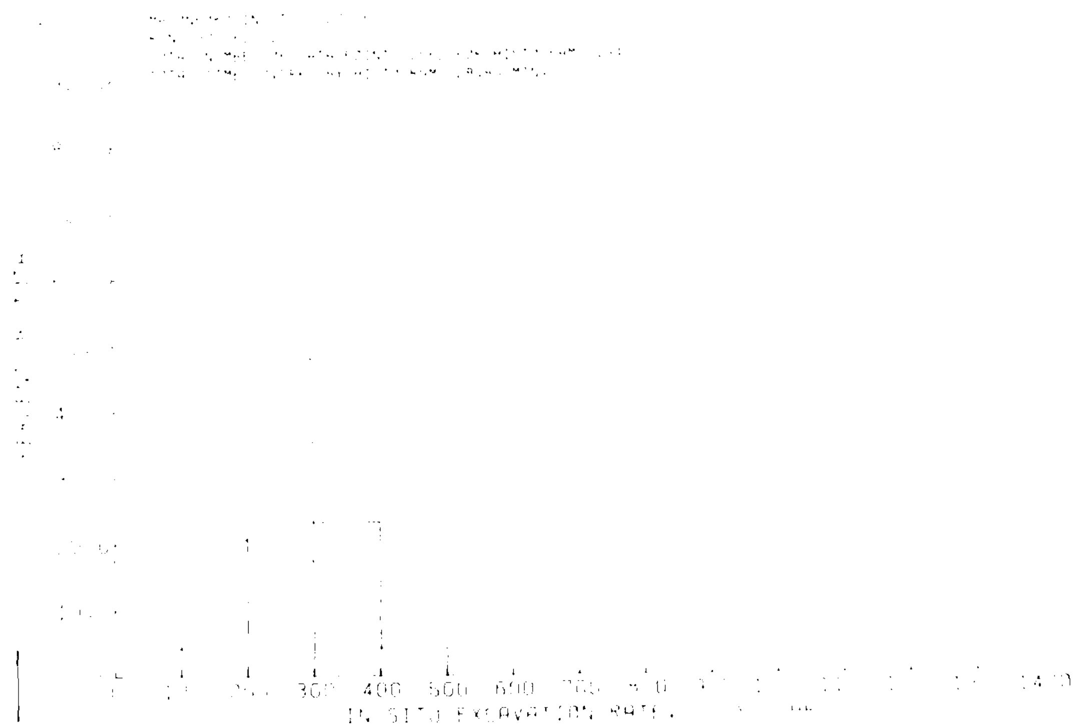
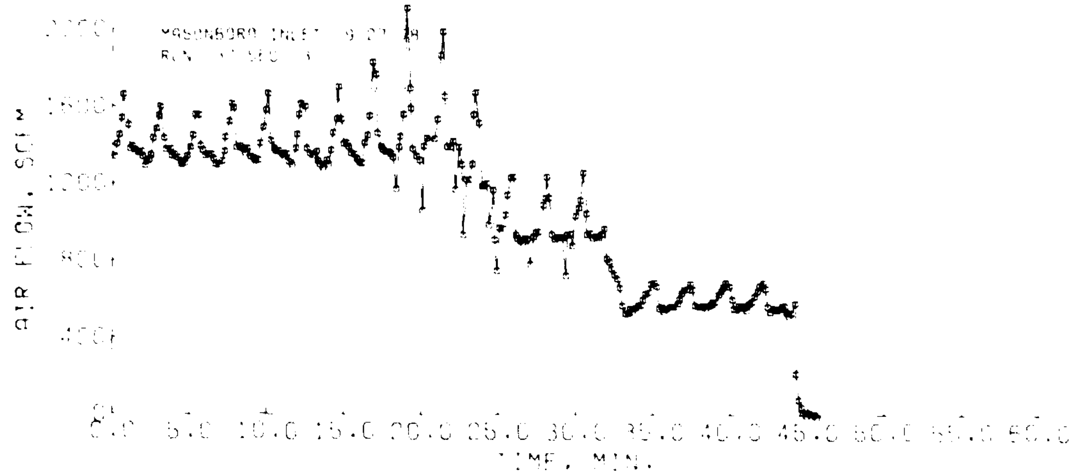
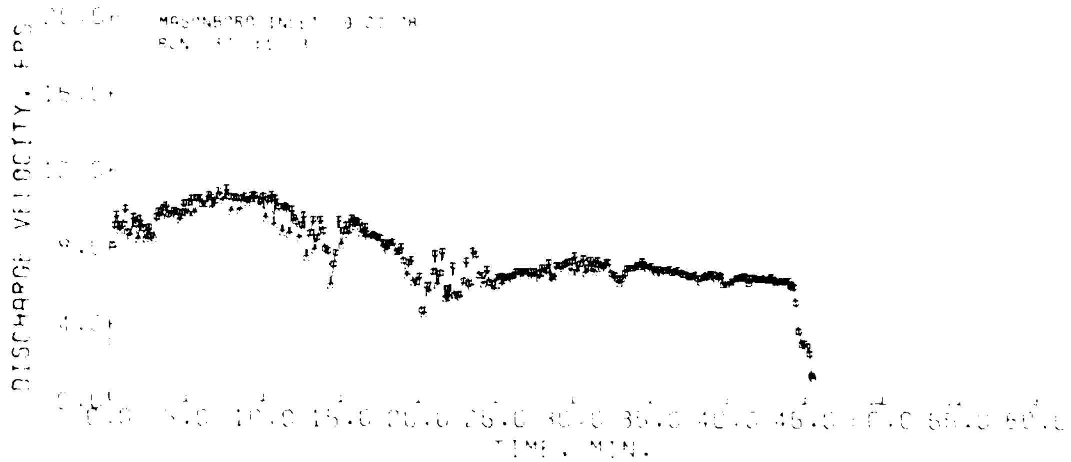


PLATE A40





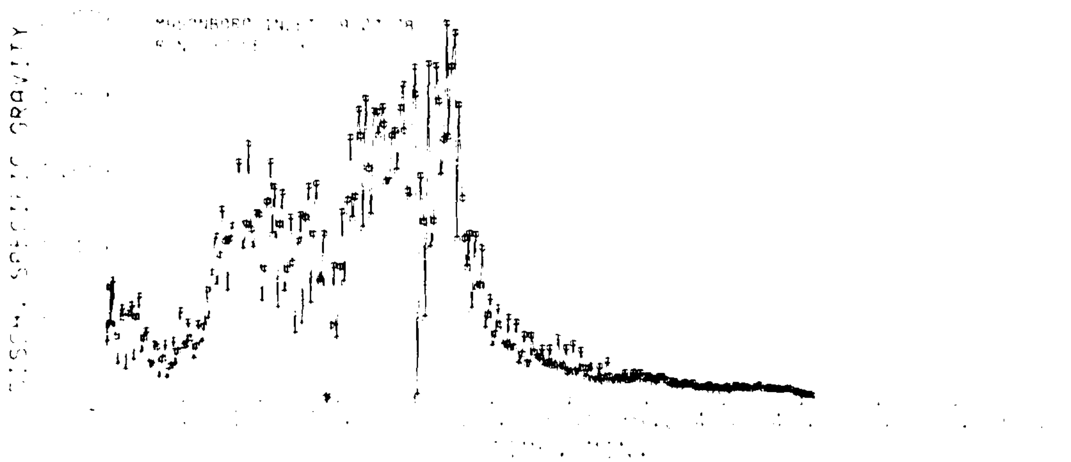
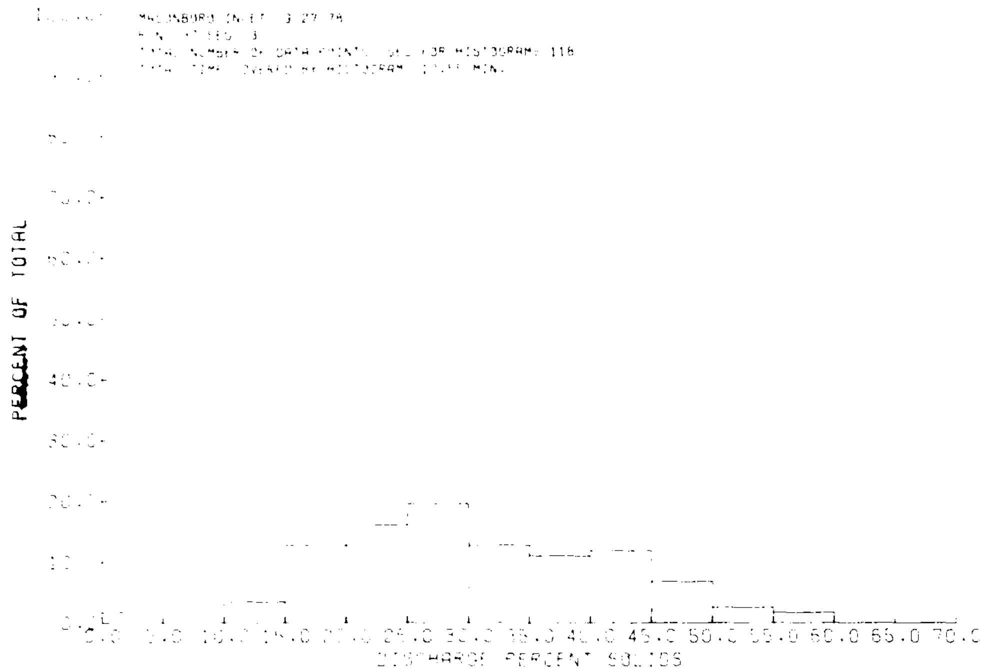
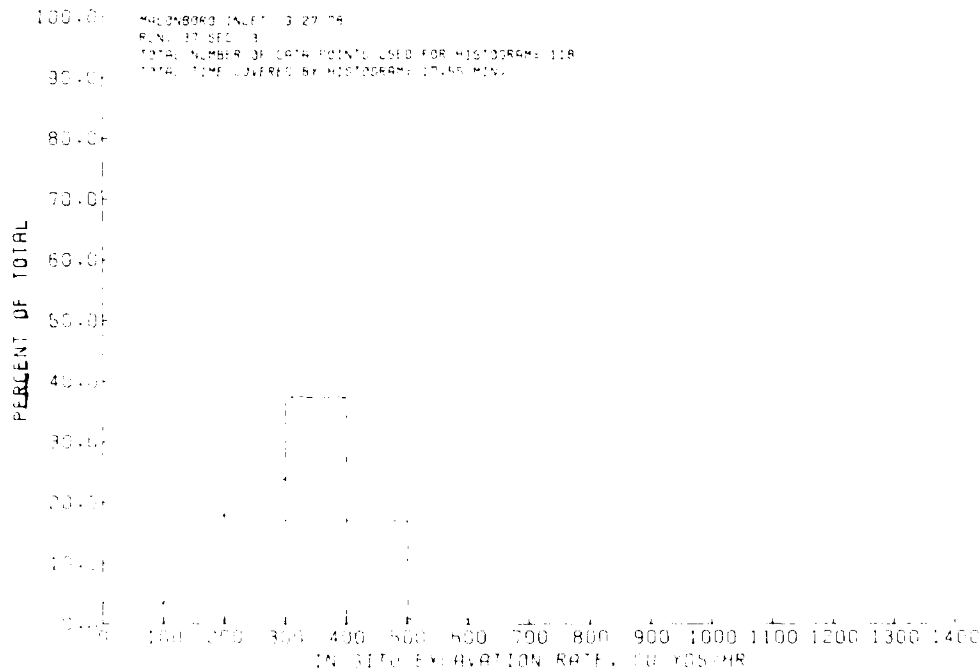


PLATE A41

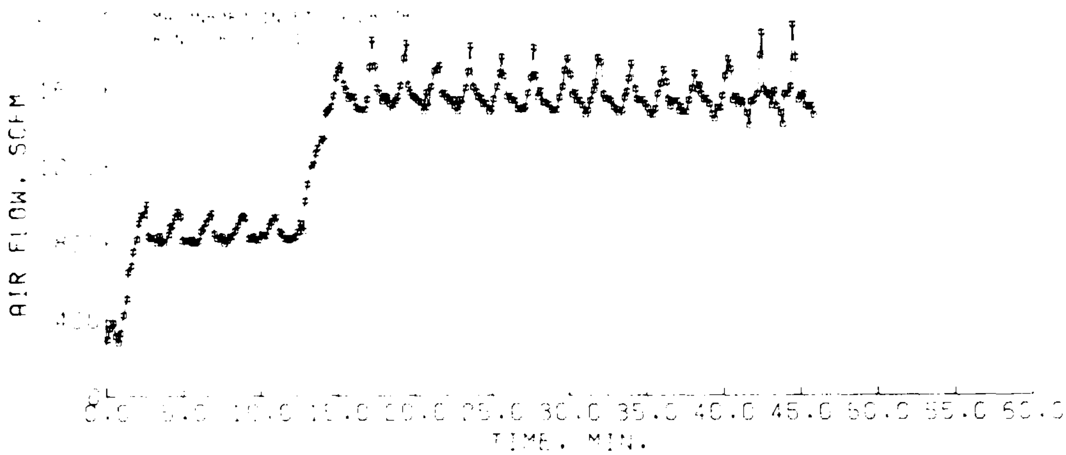


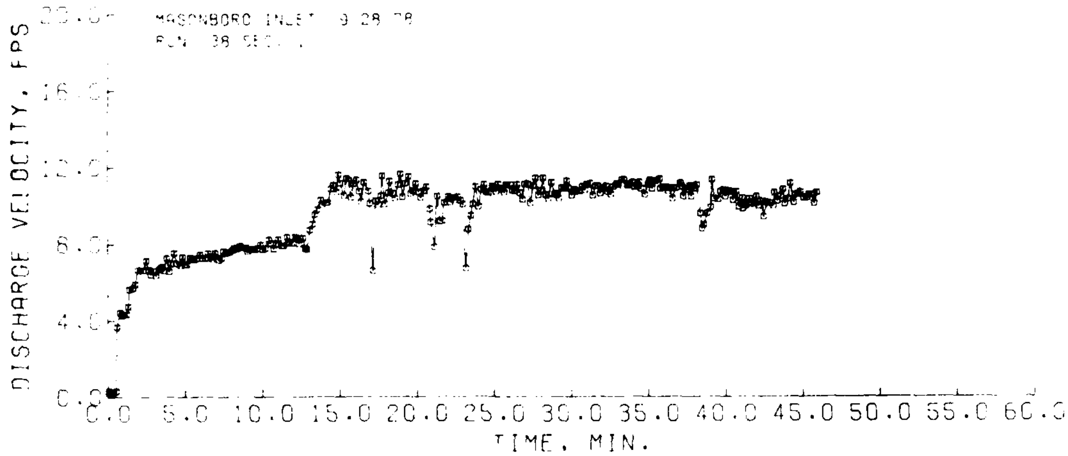
PERCENT OF TOTAL
40.0
30.0
45.0 50.0
60.0 65.0 70.0

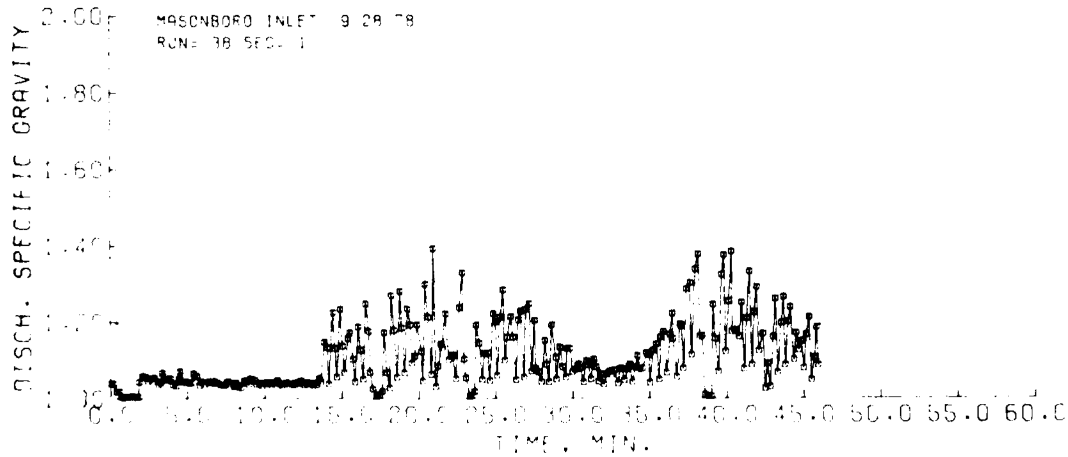


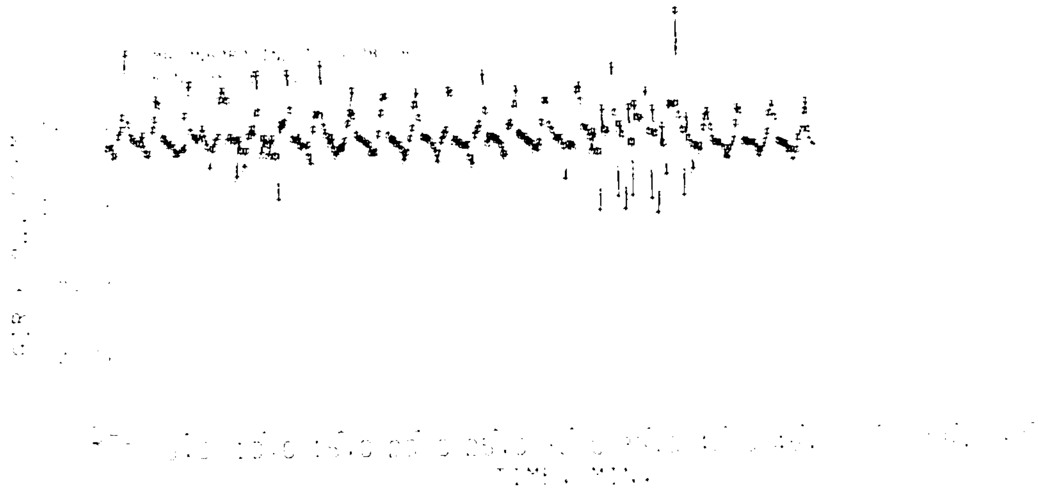
100.0
90.0
80.0
70.0
60.0
50.0
PERCENT OF TOTAL
400
700 800 900 1000 1100 1200 1300

PLATE A42


AIR FLOW, SCFM
TIME, MIN.


MASONBORO INLET 9 28 78
DISCHARGE VELOCITY, FPS
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


MASONBORO INLET 9 28 78
RUN= 38 SEC. 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
50.0 55.0 60.0
TIME, MIN.



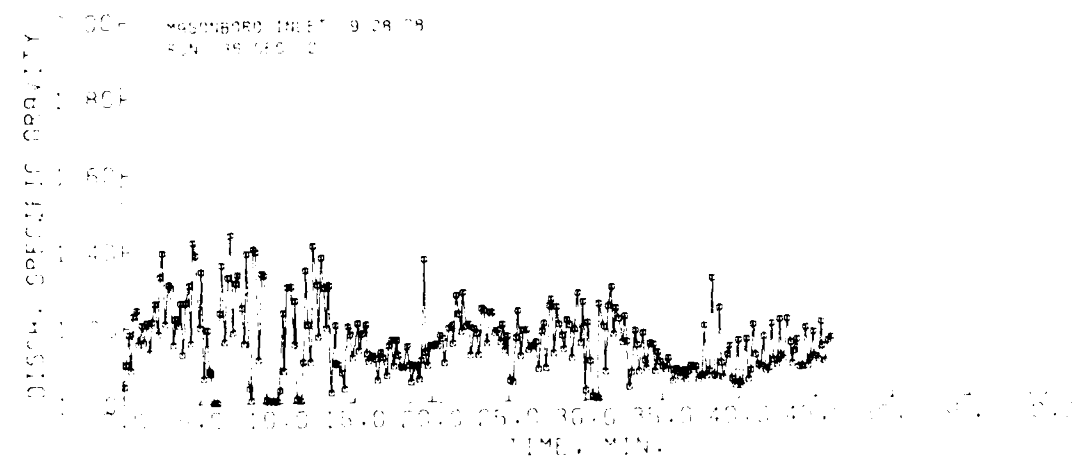
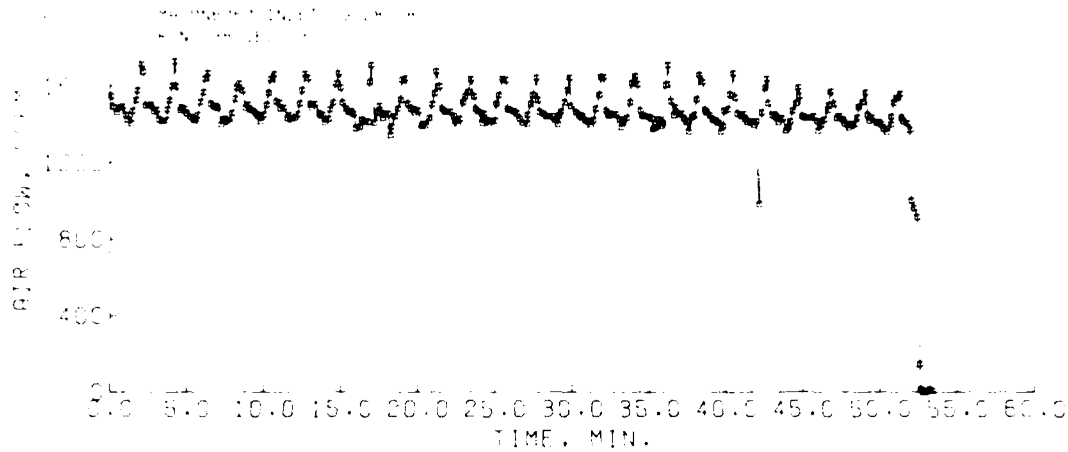
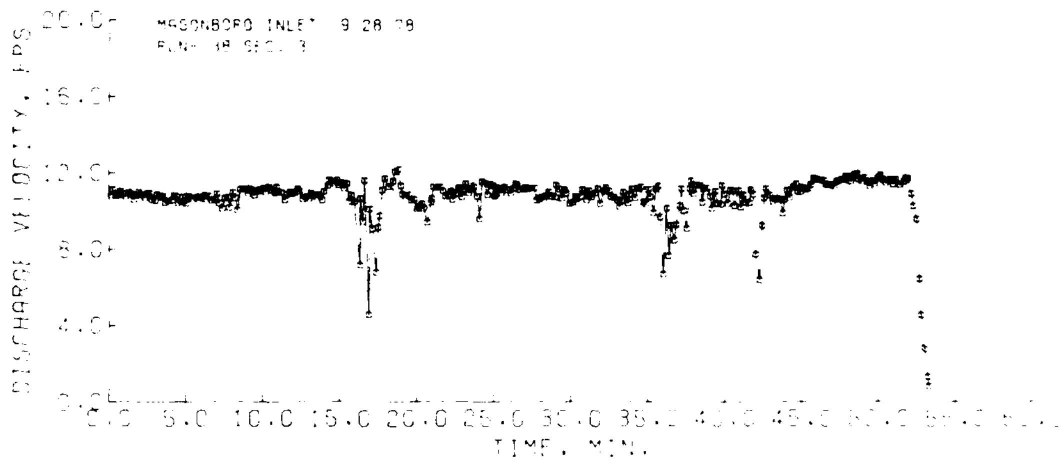


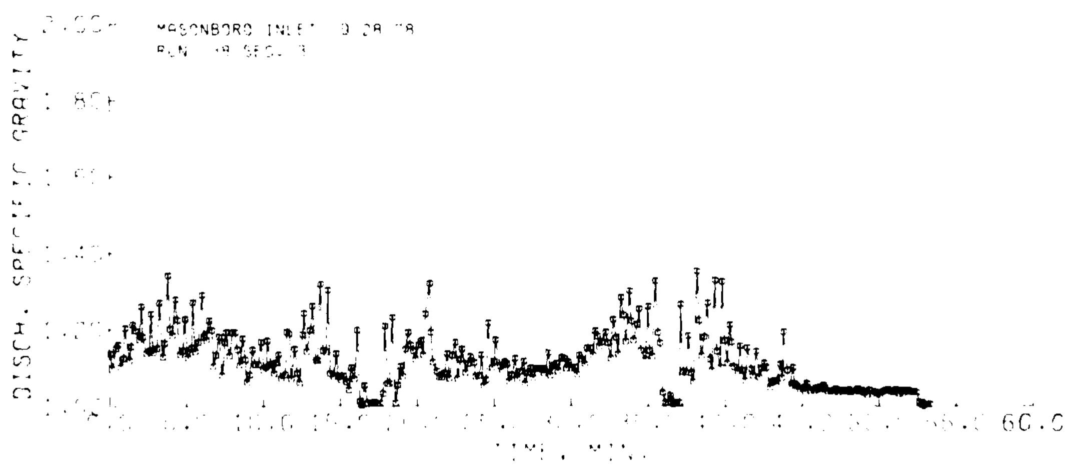
PLATE A44



800
400
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

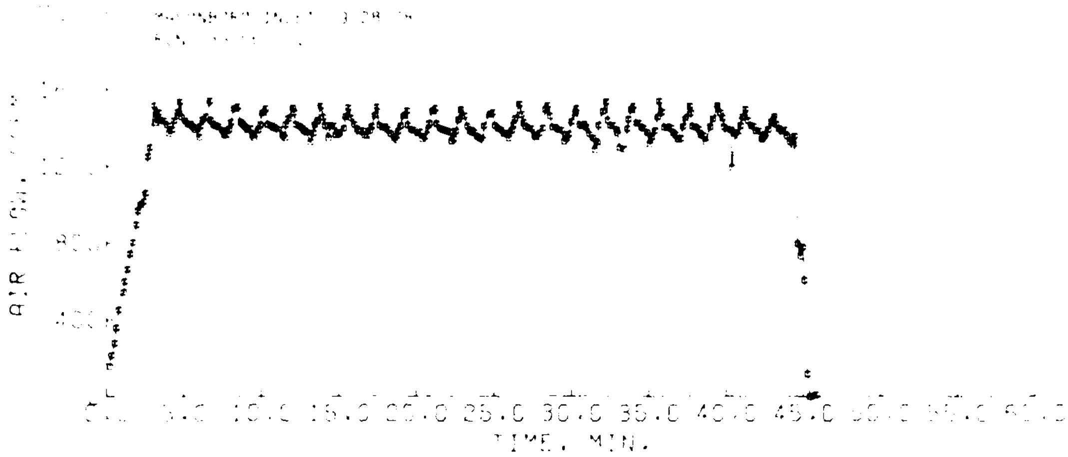


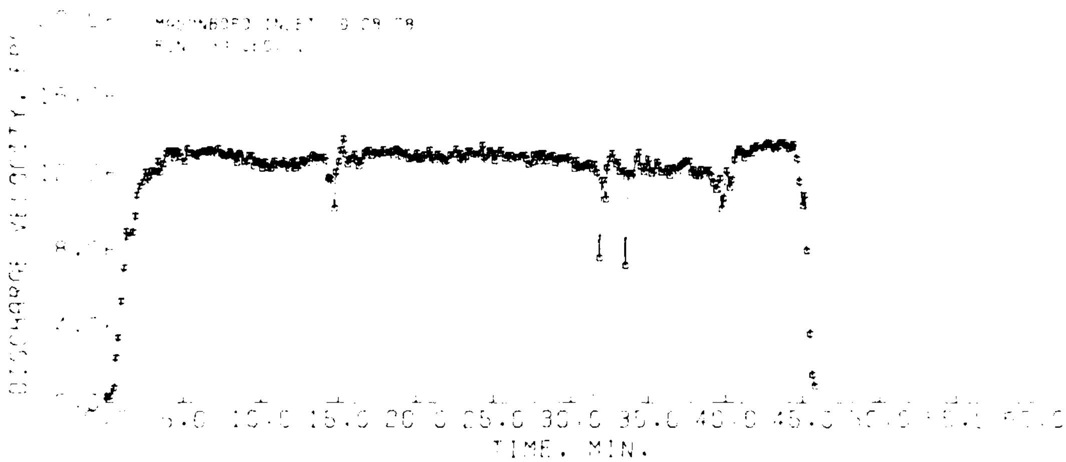
MASONBORO INLET 9 28 78
16.0
8.0
4.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0
TIME, MIN.



MASONBORO INLET 9 28 78
DISCH. SPECIFIC GRAVITY
10.0
60.0

PLATE A45





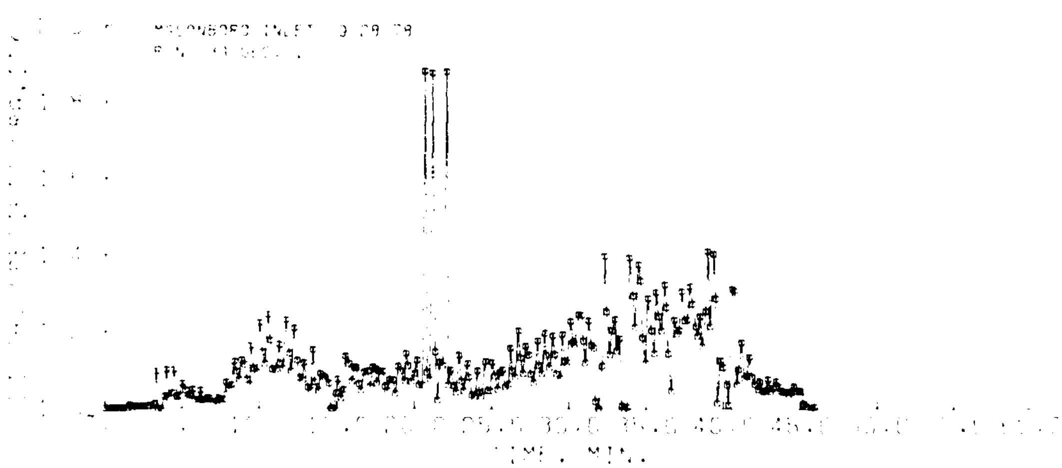
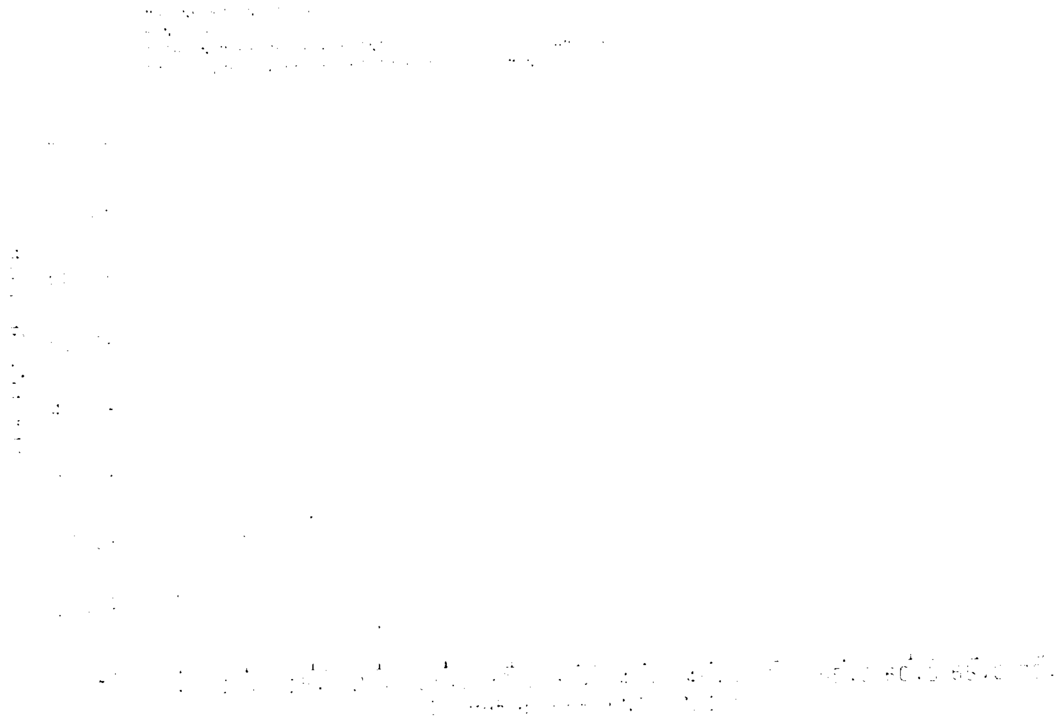


PLATE A46



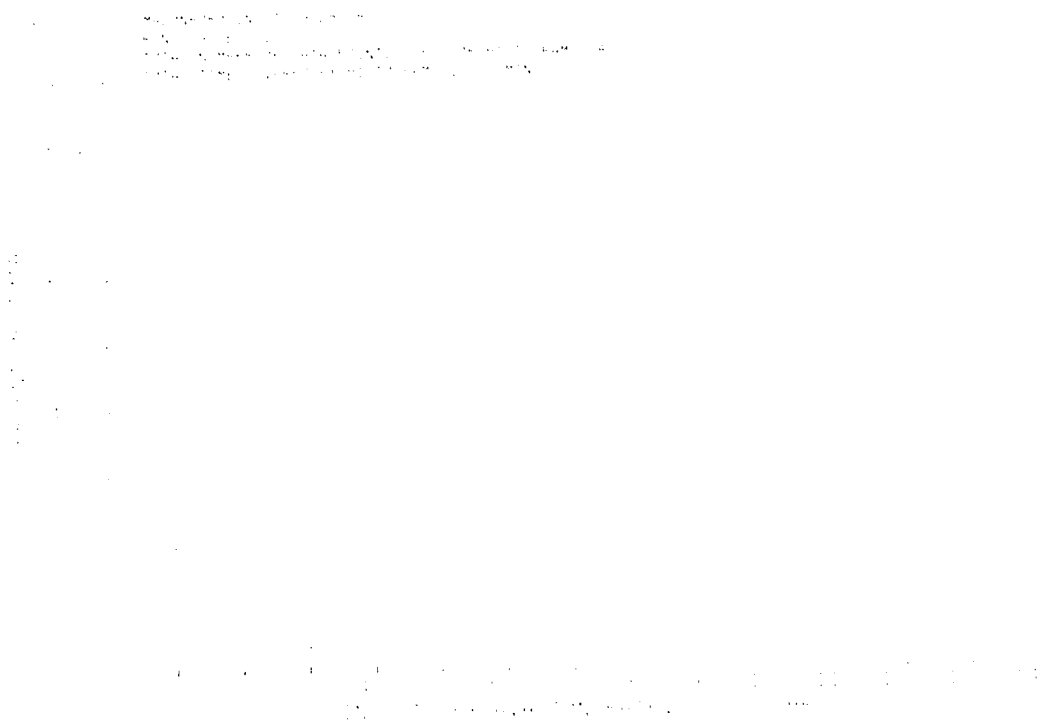
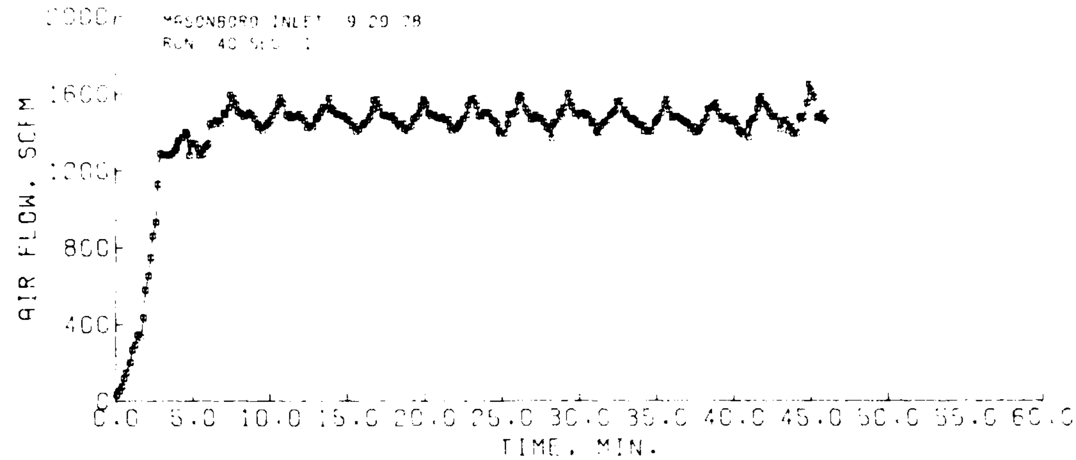
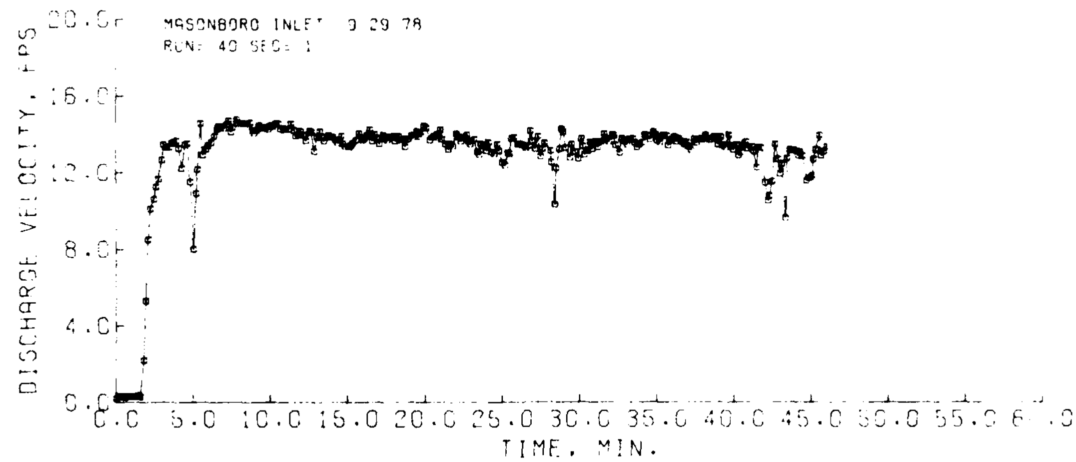


PLATE A47


MASONBORO INLET 9 29 78
RUN= 40 SEC= 1
AIR FLOW, SCFM
TIME, MIN.


MASONBORO INLET 9 29 78
RUN= 40 SEC= 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

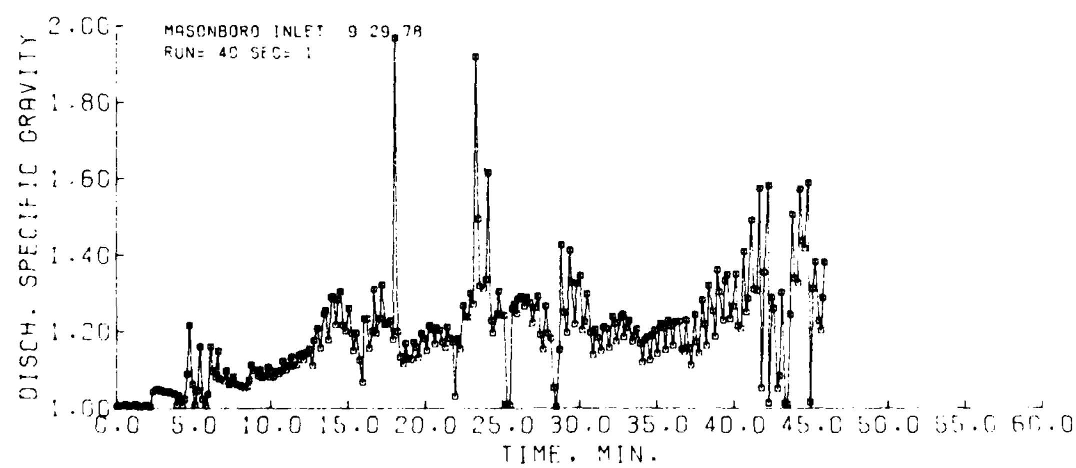
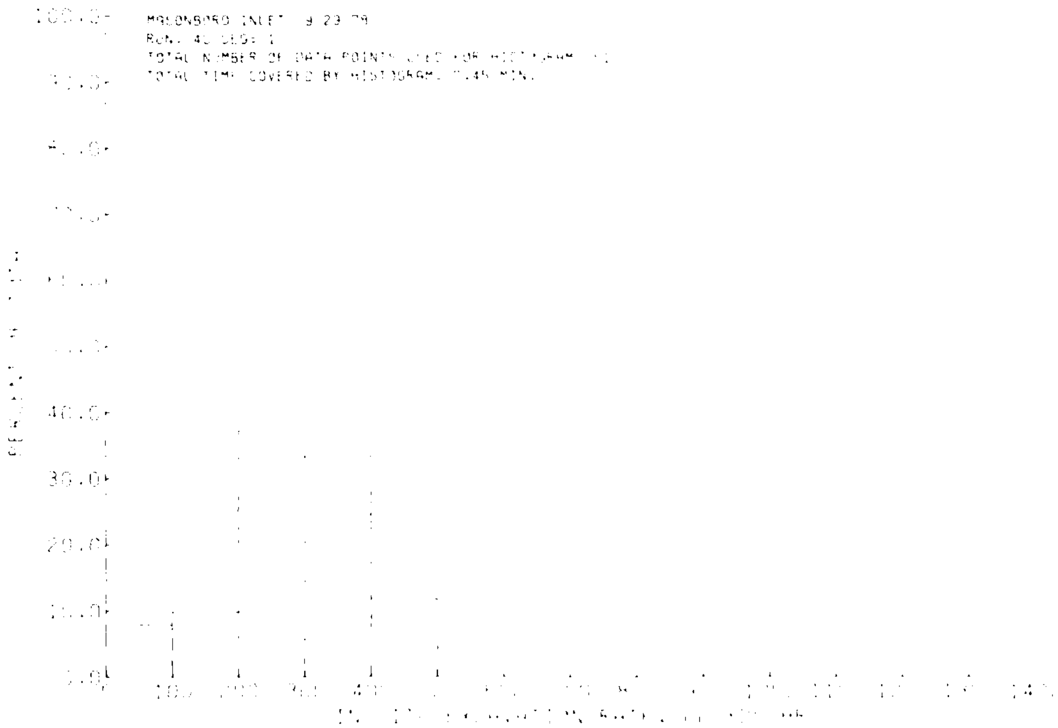
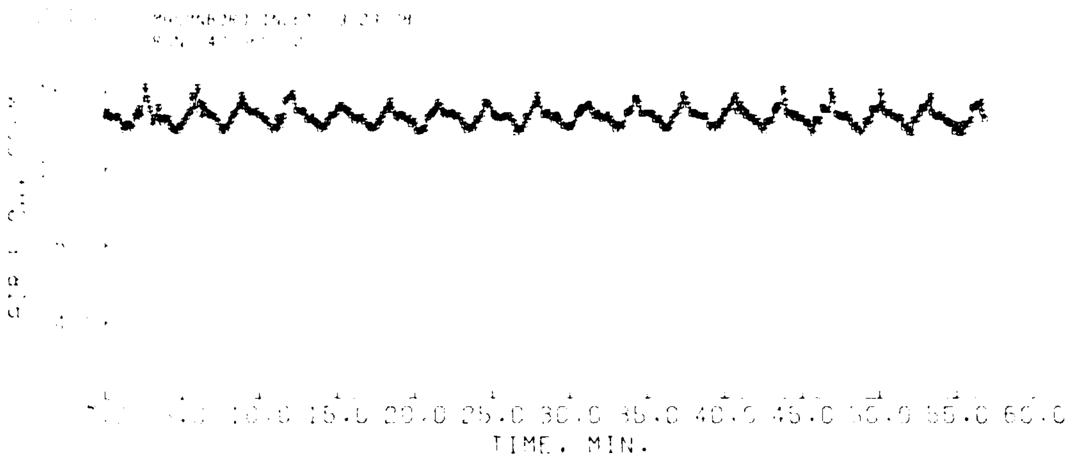
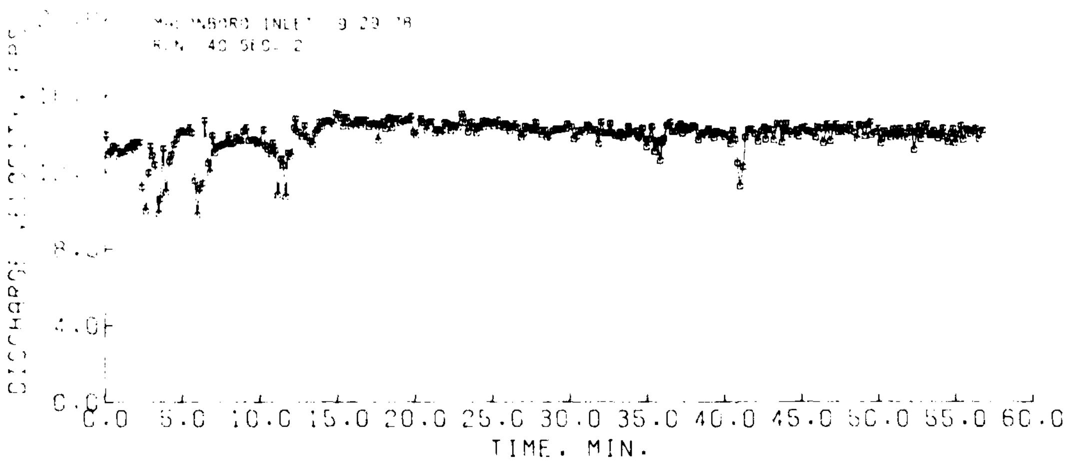

MASONBORO INLET 9 29 78
RUN= 40 SEC= 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A48


40.0


TOTAL NUMBER OF DATA POINTS
TOTAL TIME COVERED BY HISTOGRAM
40.0
30.0
20.0
10.0


TIME, MIN.


MASONBORO INLET 9 29 78
RUN= 40 SEC= 2
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
TIME, MIN.

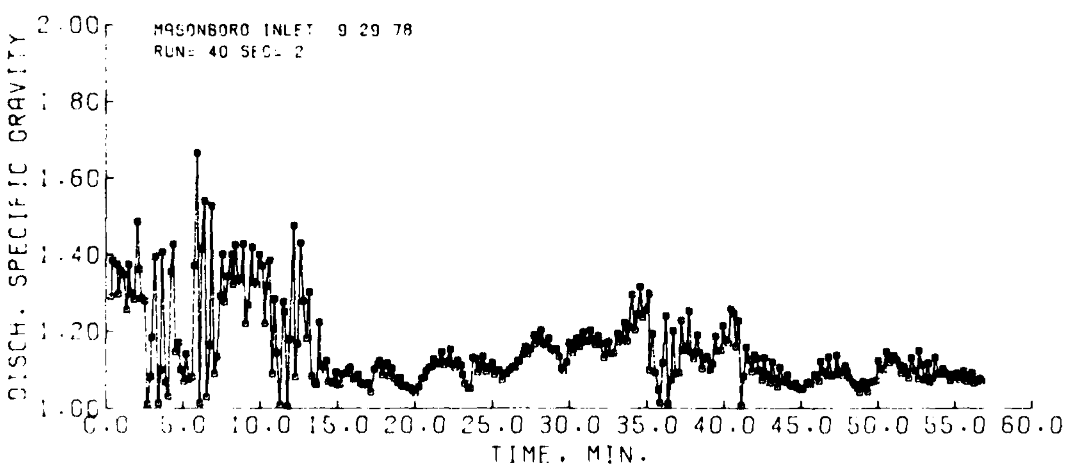
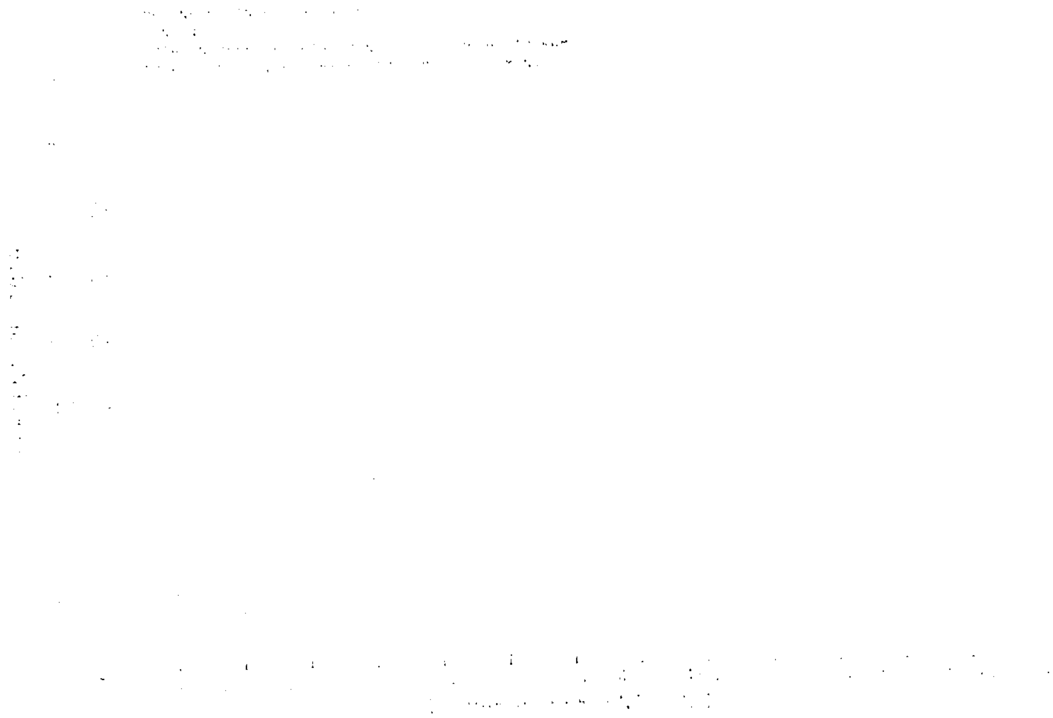

MASONBORO INLET 9 29 78
RUN= 40 SEC= 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
TIME, MIN.

PLATE A50



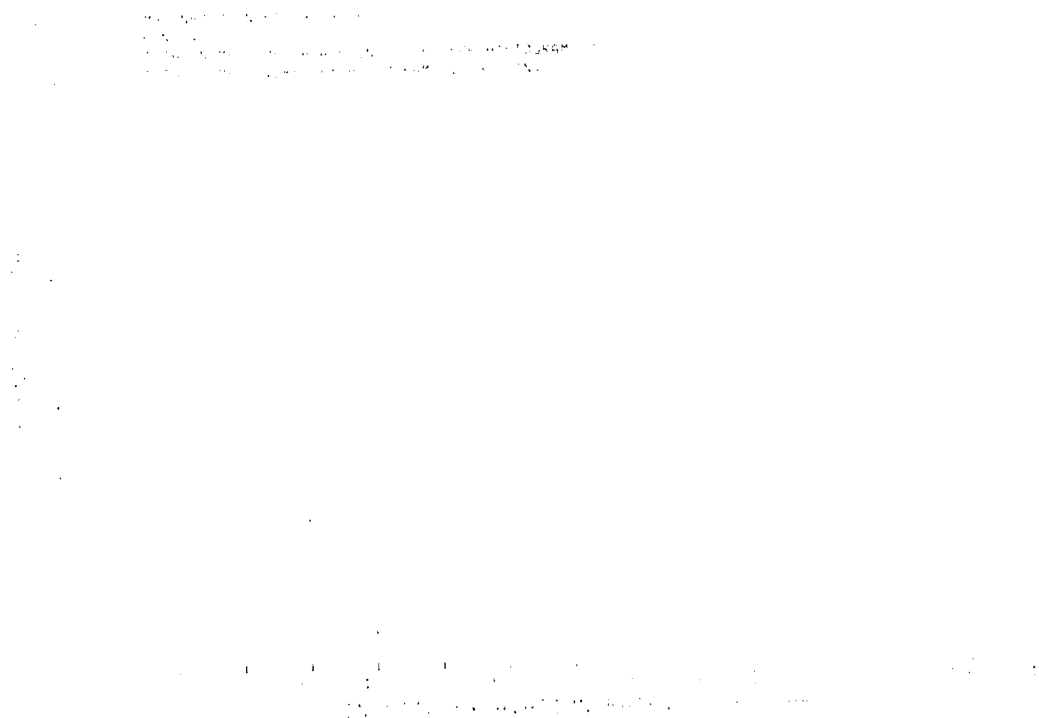
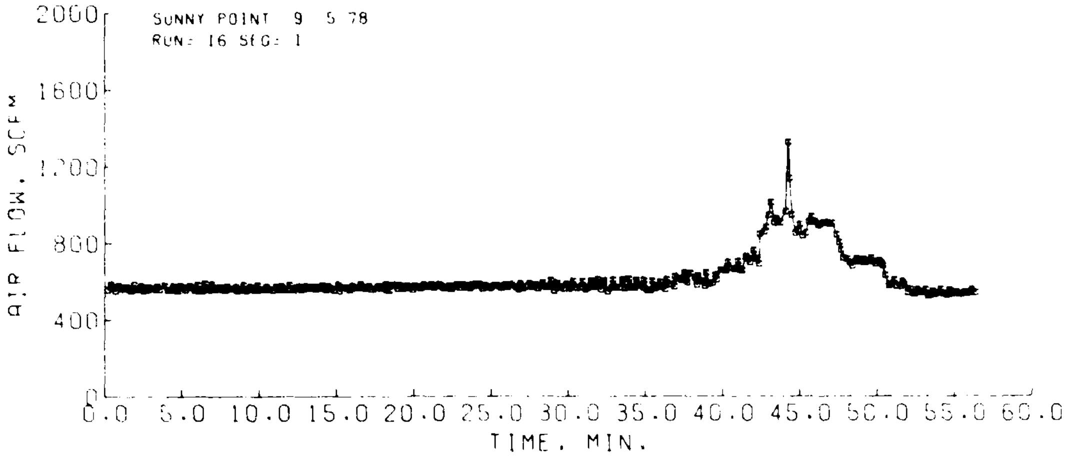
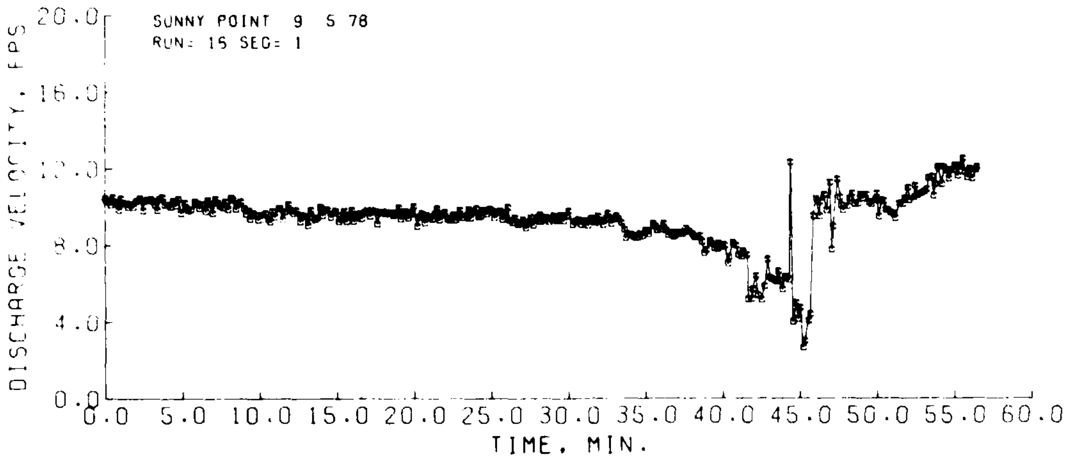


PLATE A51


SUNNY POINT 9 5 78
RUN= 16 SEG= 1
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 9 5 78
RUN= 16 SEG= 1
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

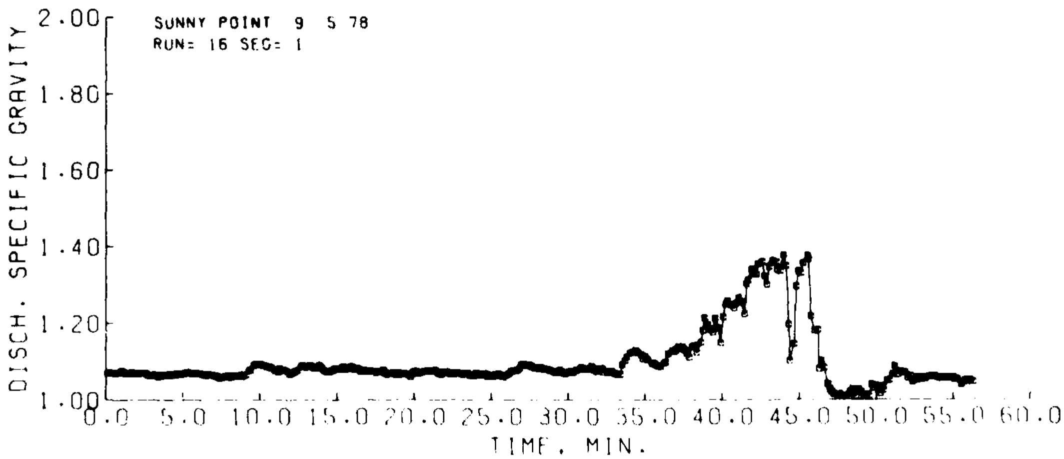
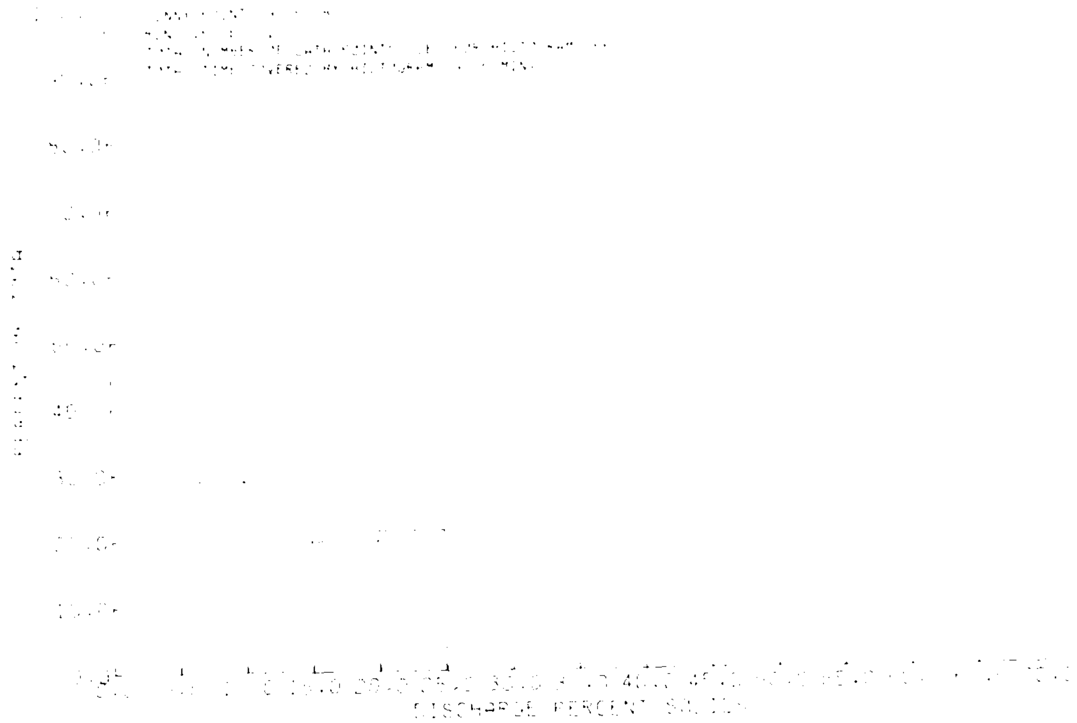

SUNNY POINT 9 5 78
RUN= 16 SEG= 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A52



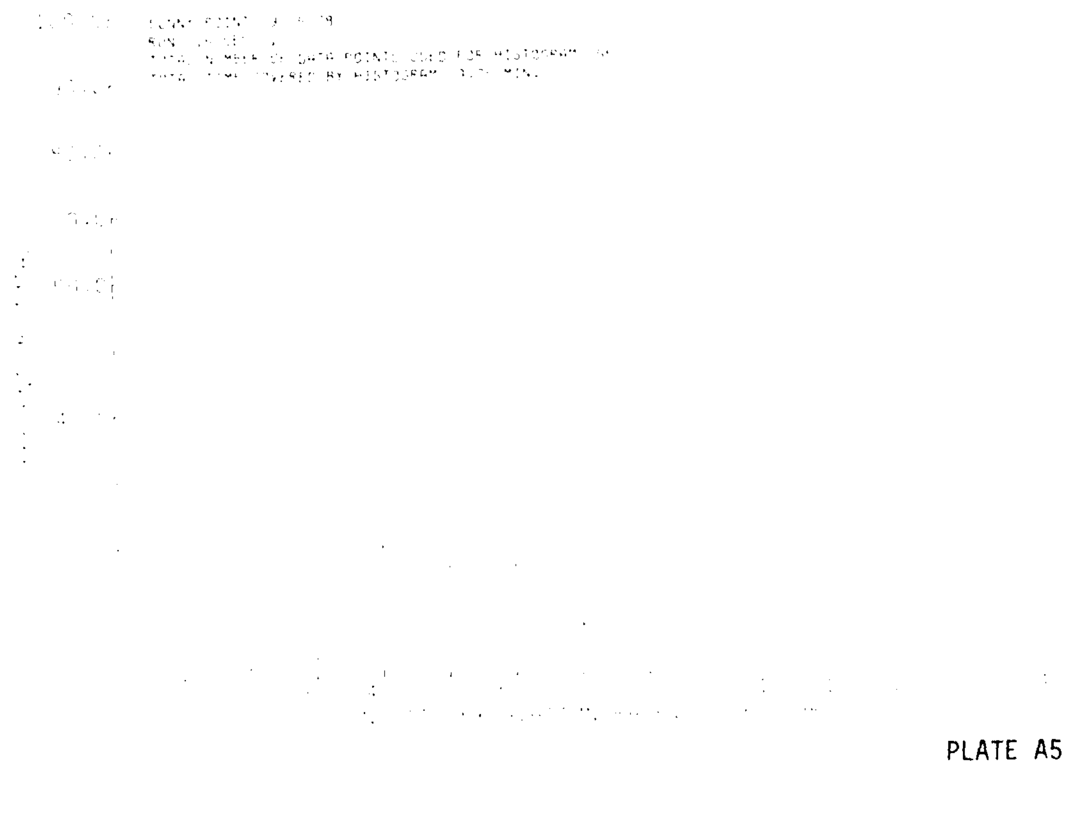
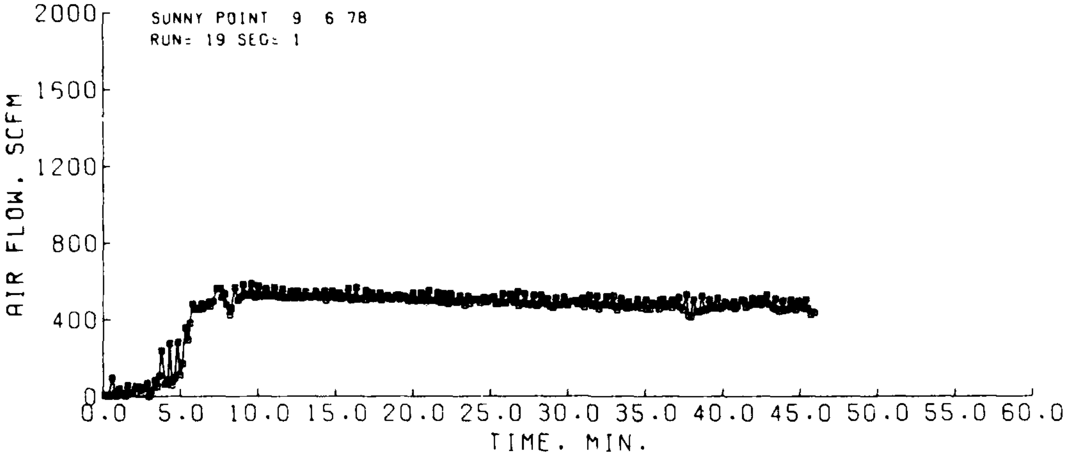
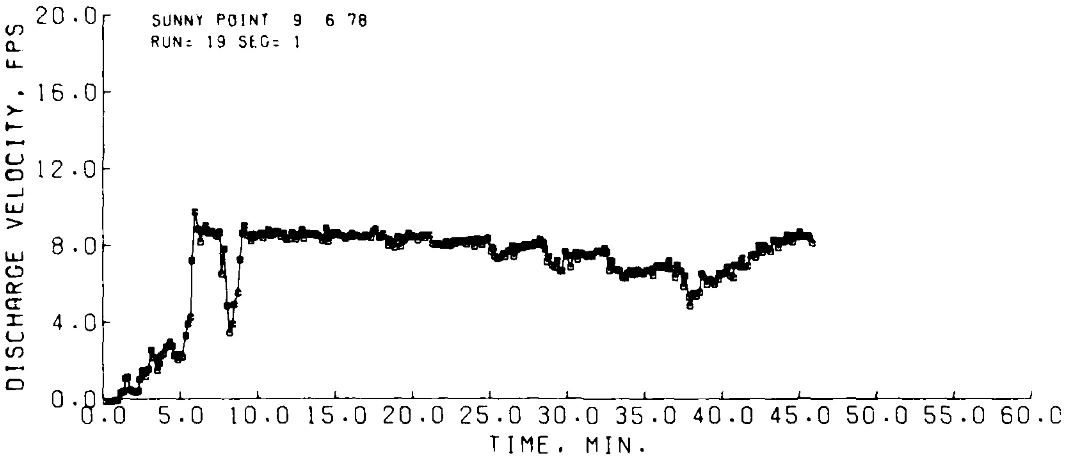


PLATE A53


SUNNY POINT 9 6 78
RUN= 19 SEG= 1
AIR FLOW, SCFM
0
400
800
1200
1600
2000
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 9 6 78
RUN= 19 SEG= 1
DISCHARGE VELOCITY, FPS
0.0
4.0
8.0
12.0
16.0
20.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

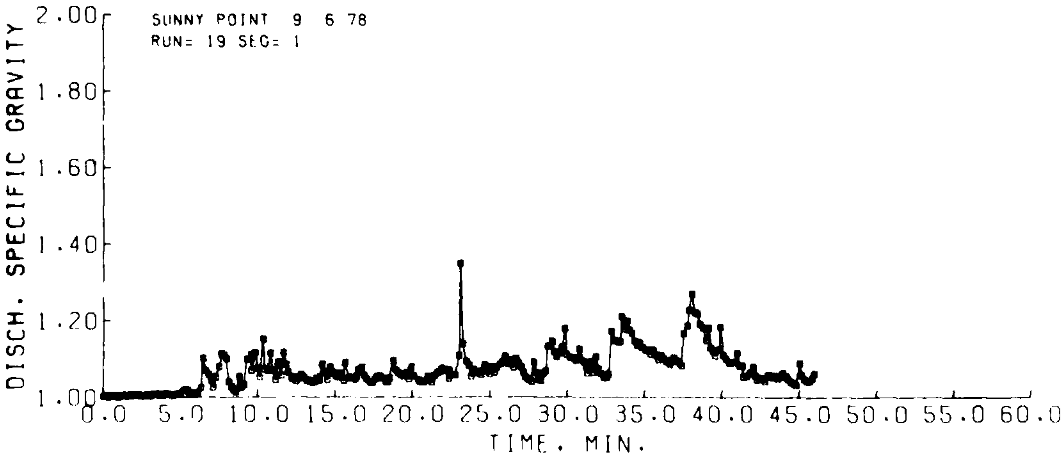
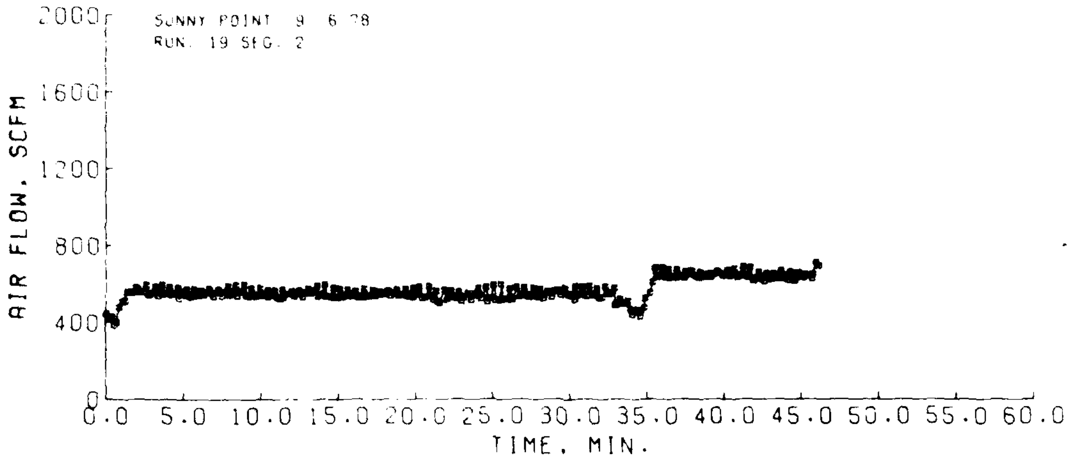
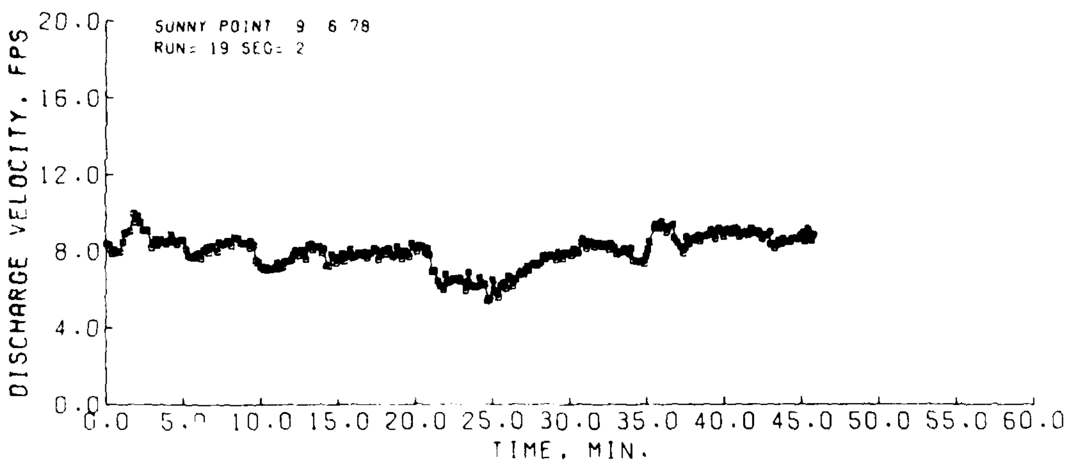

SUNNY POINT 9 6 78
RUN= 19 SEG= 1
DISCH. SPECIFIC GRAVITY
1.00
1.20
1.40
1.60
1.80
2.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A54


SUNNY POINT 9 6 78
RUN: 19 SEG: 2
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 9 6 78
RUN: 19 SEG: 2
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

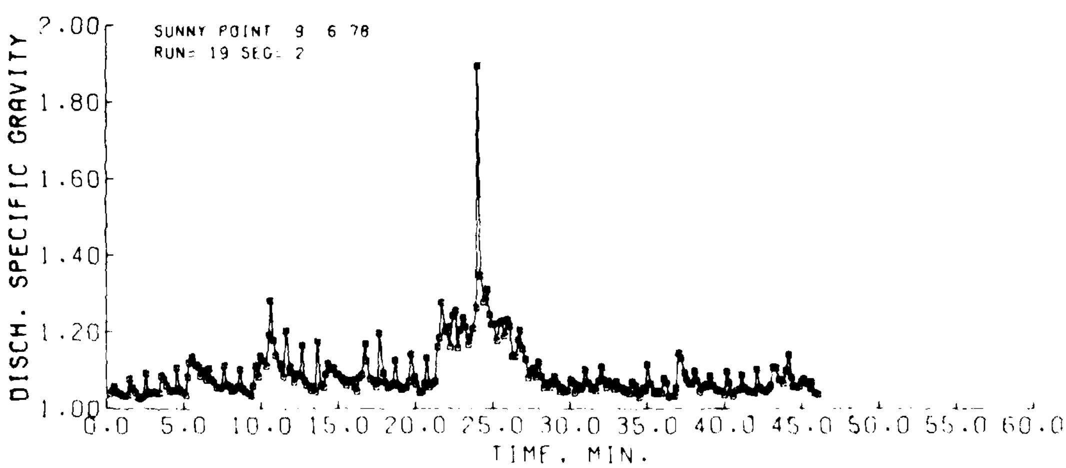

SUNNY POINT 9 6 78
RUN: 19 SEG: 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A55

PLATE A42

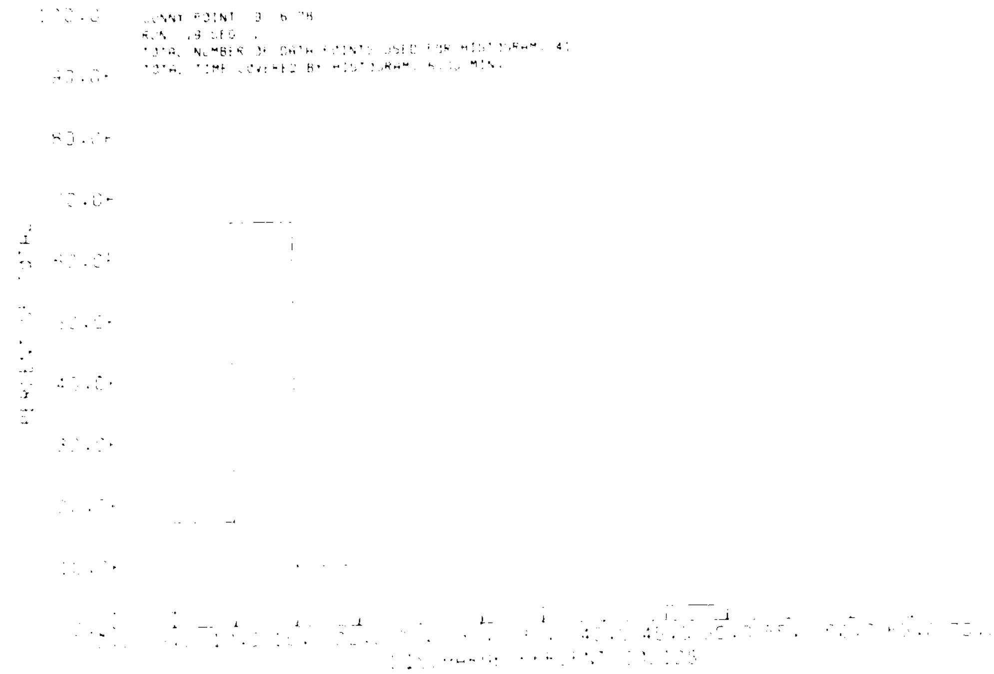
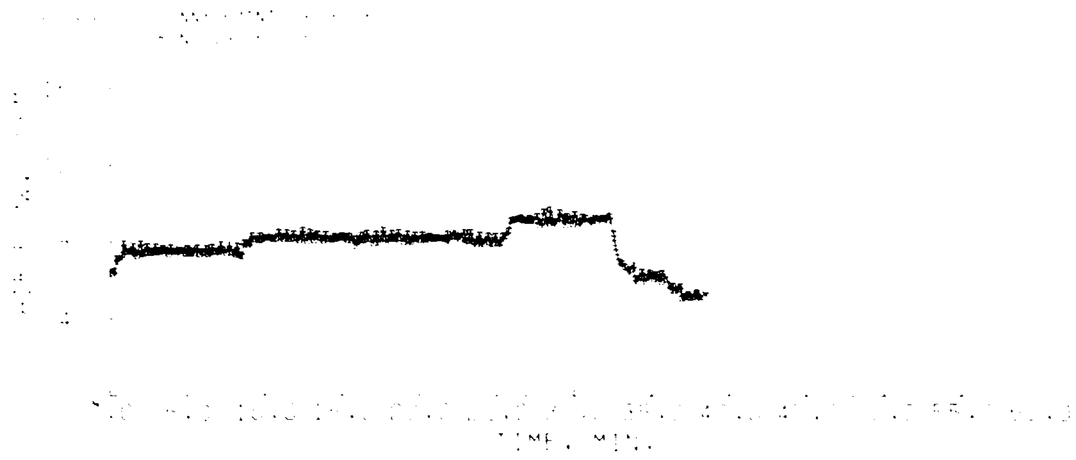
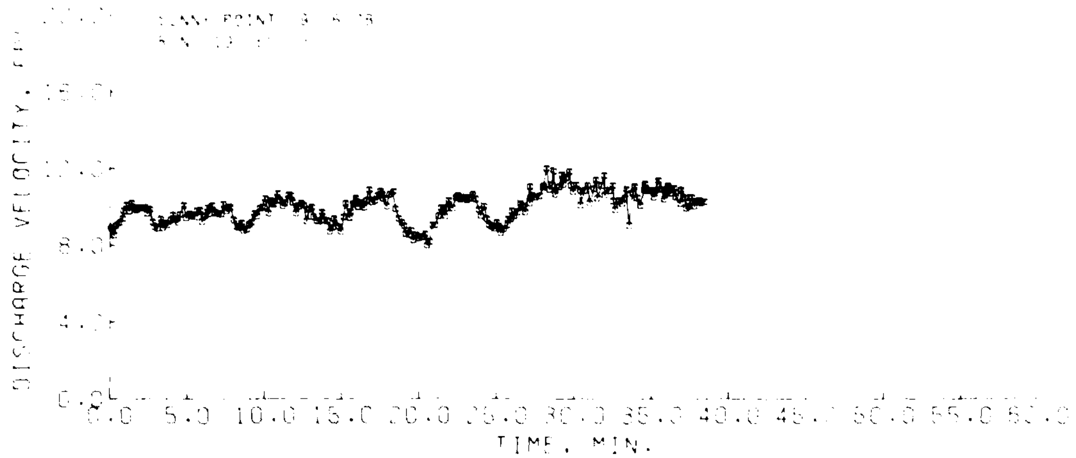


PLATE A56


TIME, MIN.


DISCHARGE VELOCITY, FPS
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

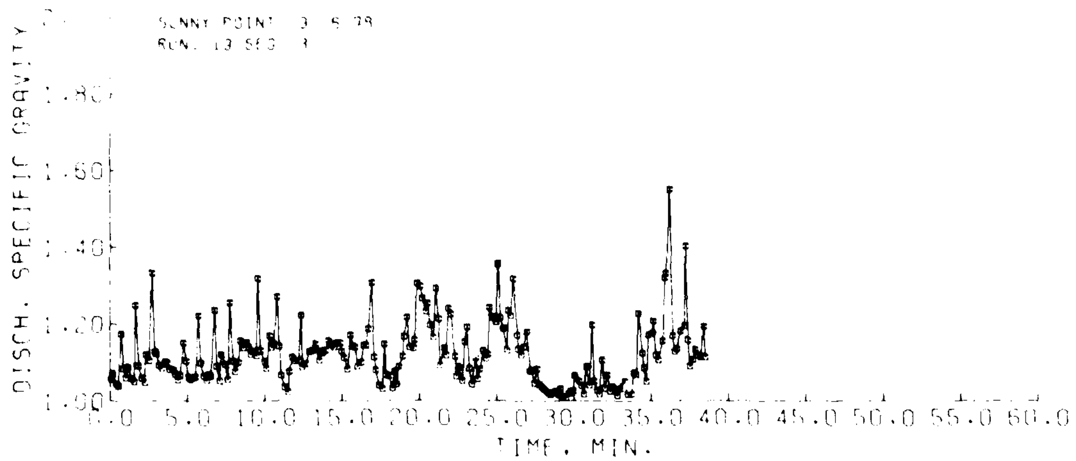
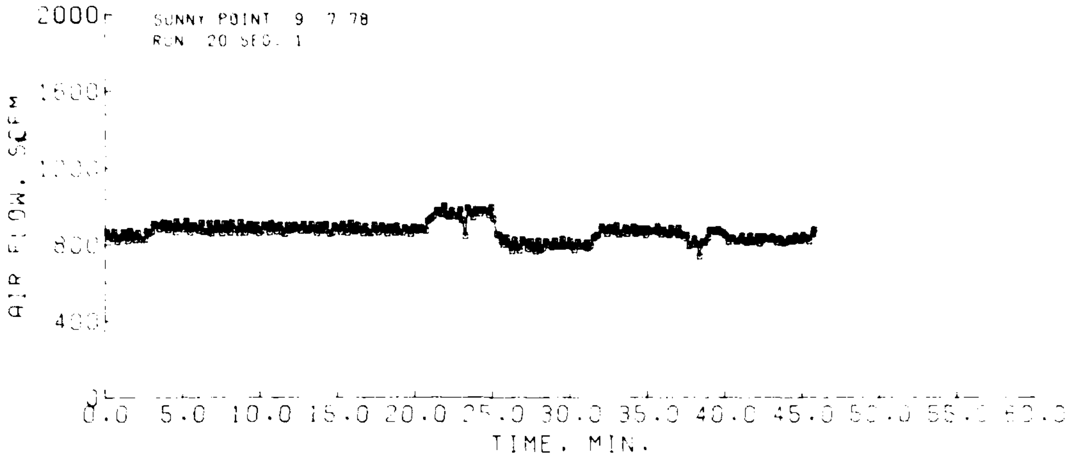
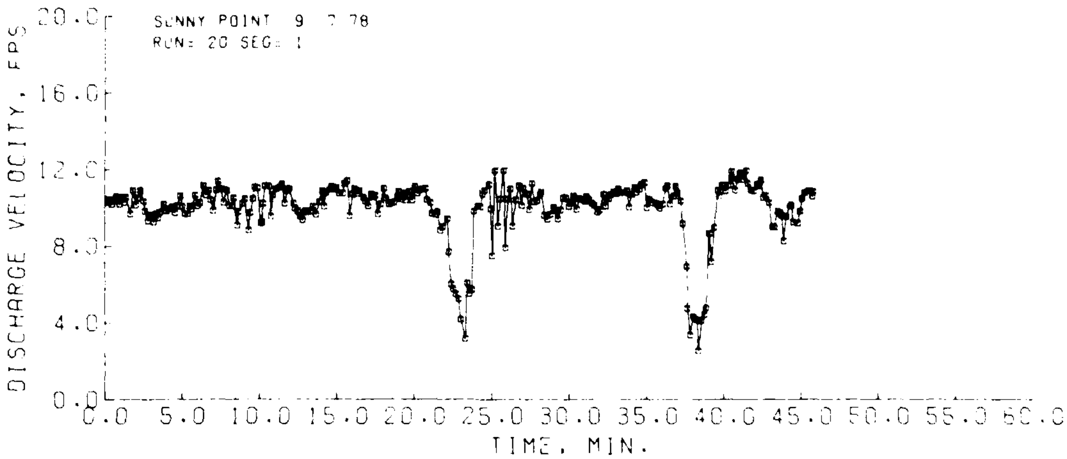

RUN 13 SEG 3
DISCH. SPECIFIC GRAVITY
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A57


SUNNY POINT 9 7 78
RUN: 20 SEG: 1
AIR FLOW, SCFM
TIME, MIN.


SUNNY POINT 9 7 78
RUN: 20 SEG: 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

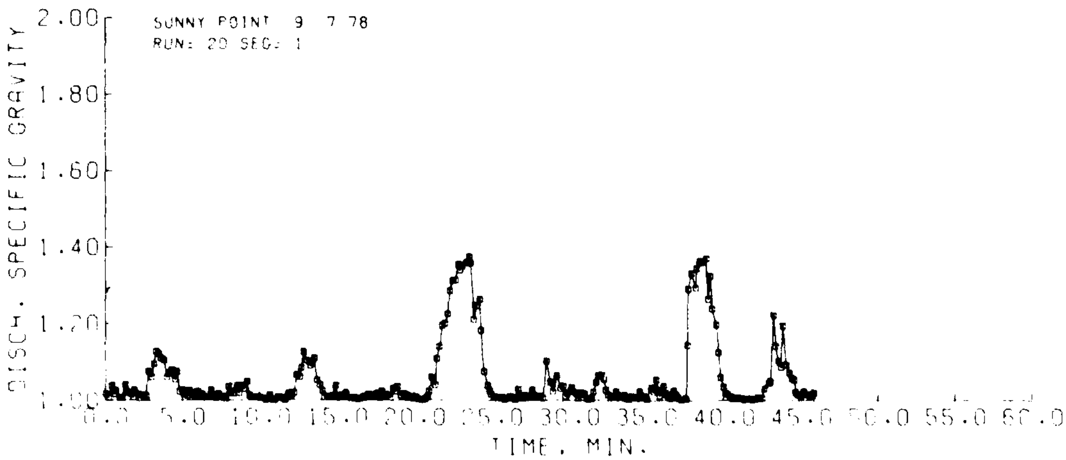
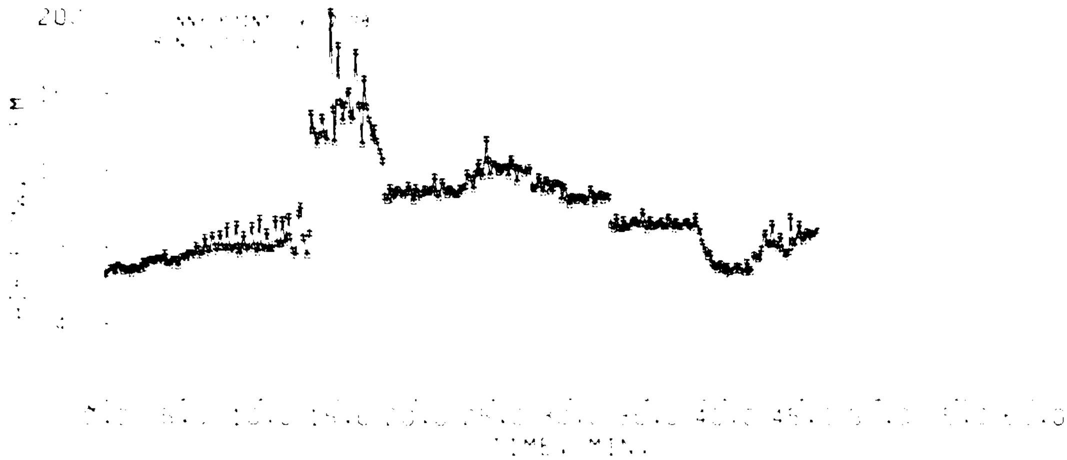
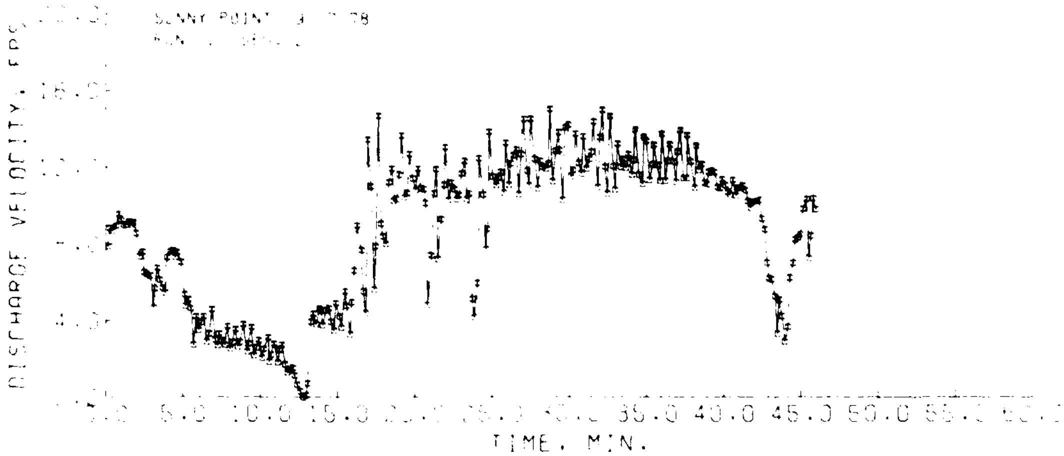

SUNNY POINT 9 7 78
RUN: 20 SEG: 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A58

PLATE A59


TIME, MIN.


DISCHARGE VELOCITY, FPS
TIME, MIN.

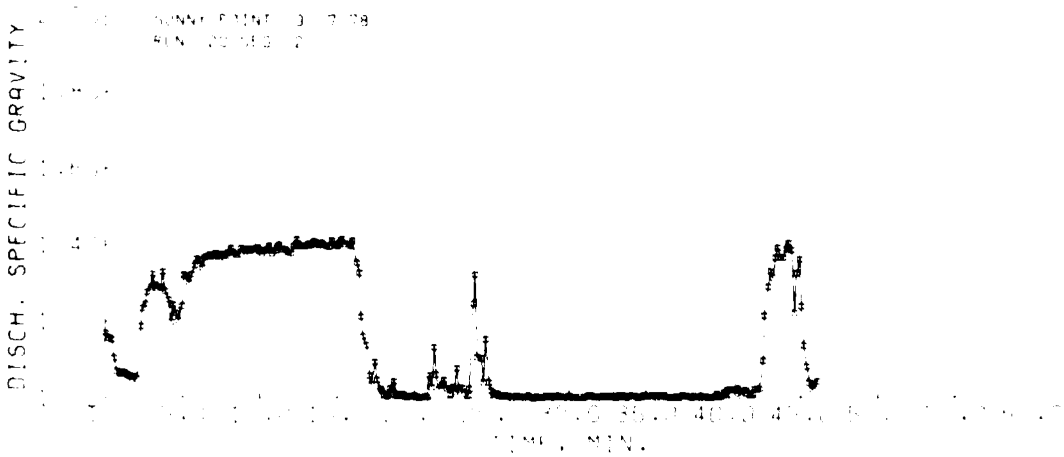
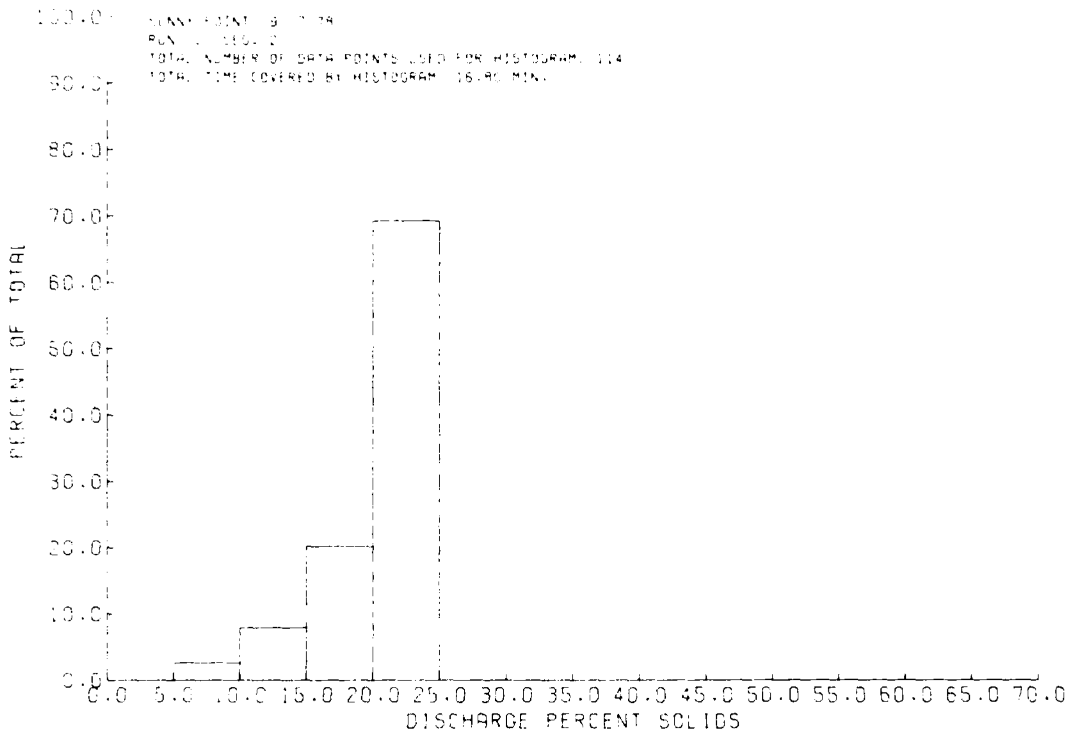

DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A60


SUNNY POINT 9 7 78
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM. 114
TOTAL TIME COVERED BY HISTOGRAM 16.80 MIN.
PERCENT OF TOTAL
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
0.0
5.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
DISCHARGE PERCENT SOLIDS

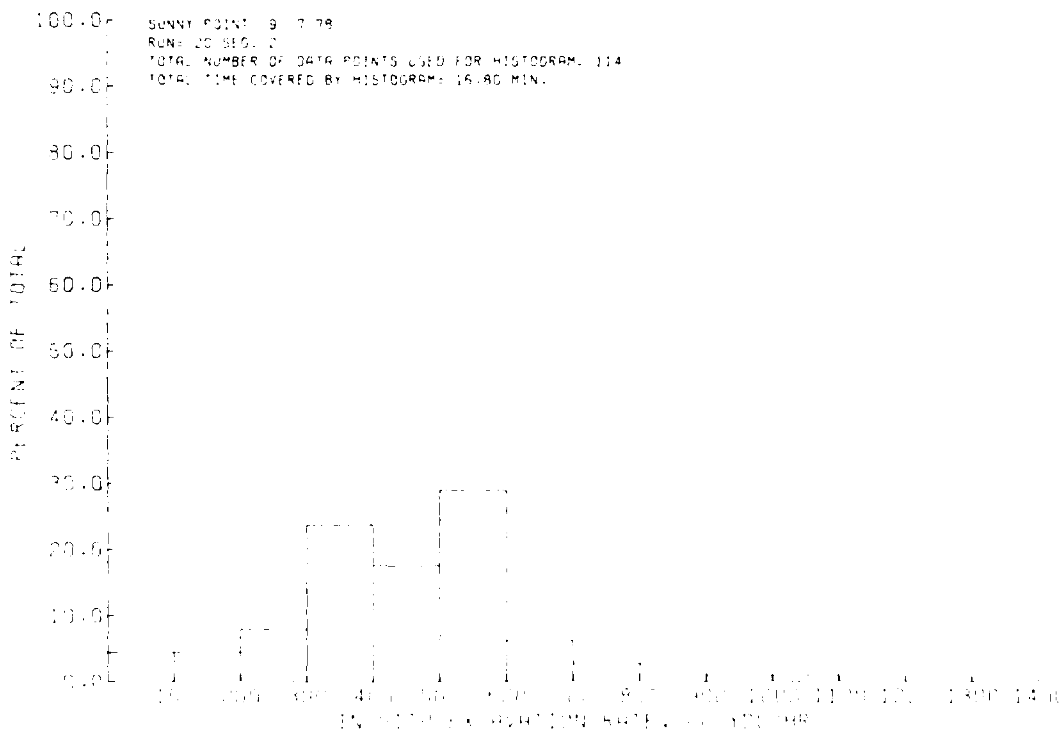
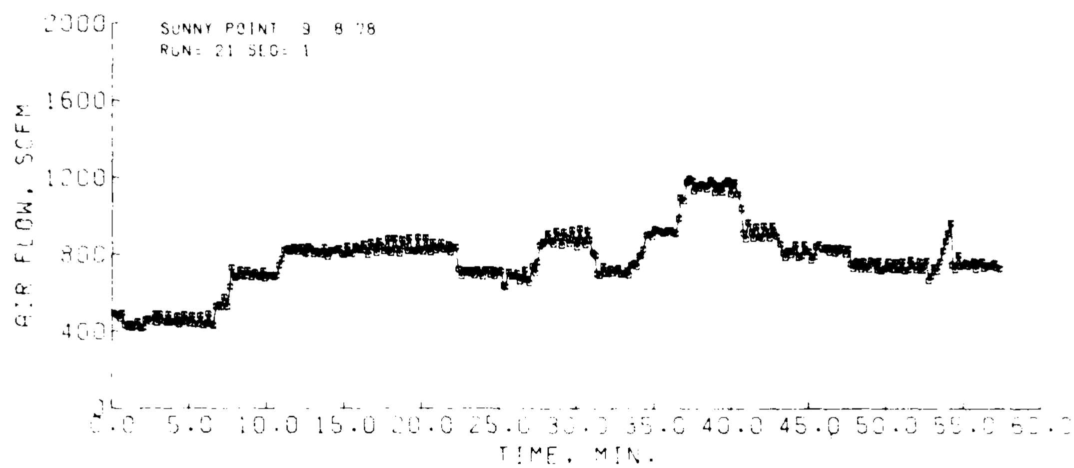
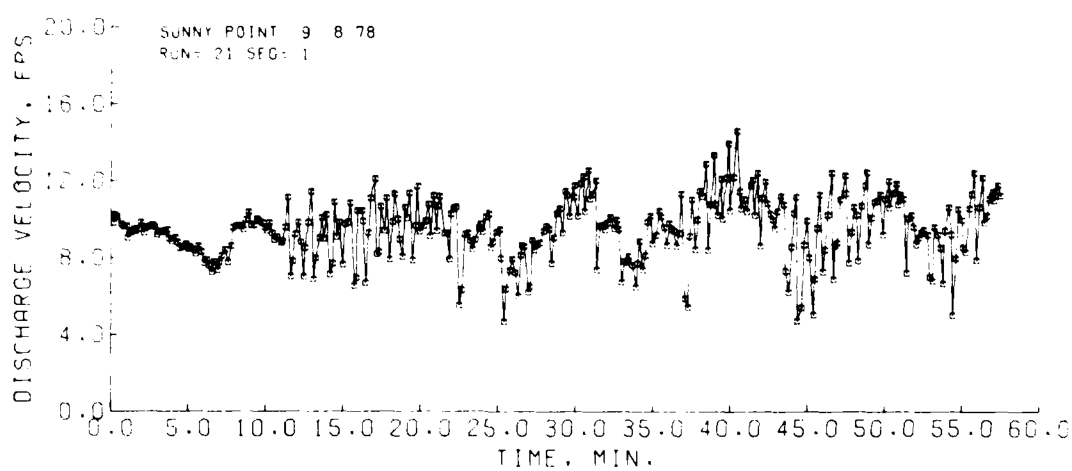

100.0
SUNNY POINT 9 7 78
RUN= 20 SEG. 2
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM. 114
TOTAL TIME COVERED BY HISTOGRAM= 16.80 MIN.
PERCENT OF TOTAL
90.0
80.0
60.0
50.0
40.0

PLATE A61


SUNNY POINT 9 8 78
RUN= 21 SEG= 1
AIR FLOW, SCFM
TIME, MIN.


SUNNY POINT 9 8 78
RUN= 21 SEG= 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

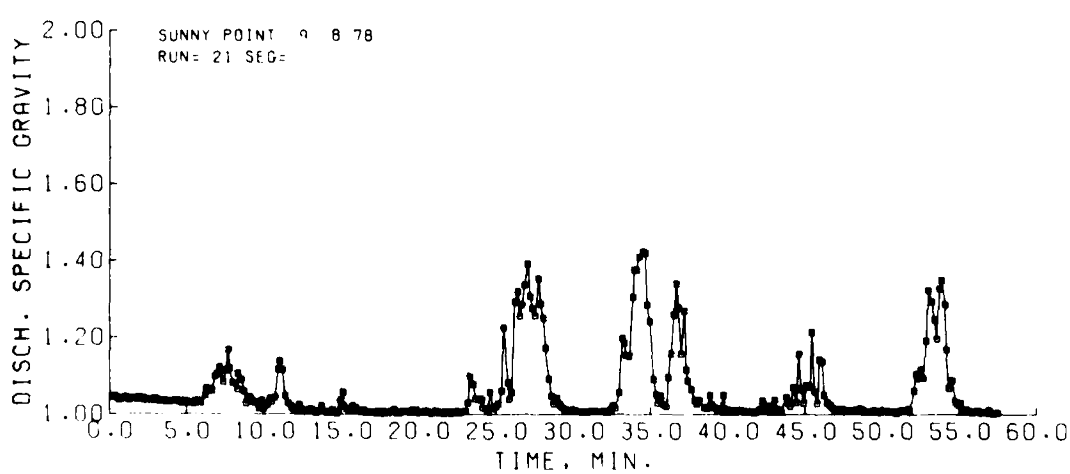

SUNNY POINT 9 8 78
RUN= 21 SEG=
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A62

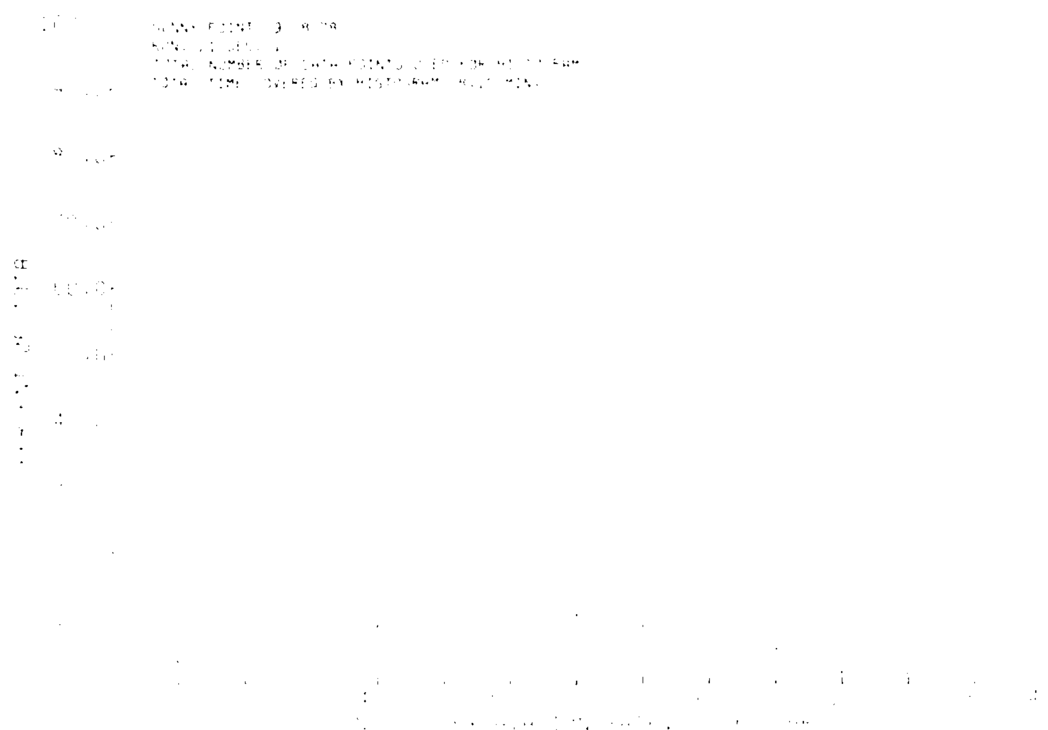
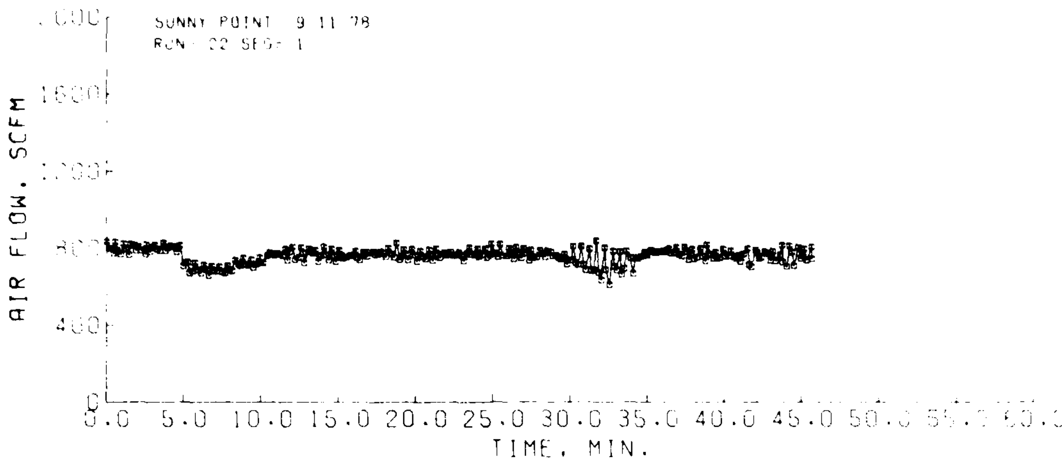
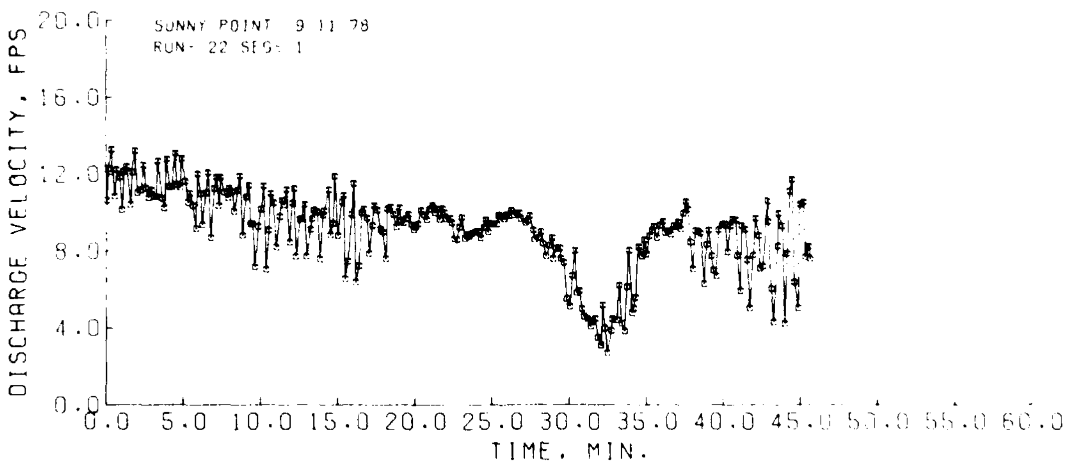


PLATE A63


SUNNY POINT 9 11 78
RUN= 22 SEG= 1
AIR FLOW, SCFM
1600
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 9 11 78
RUN= 22 SEG= 1
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

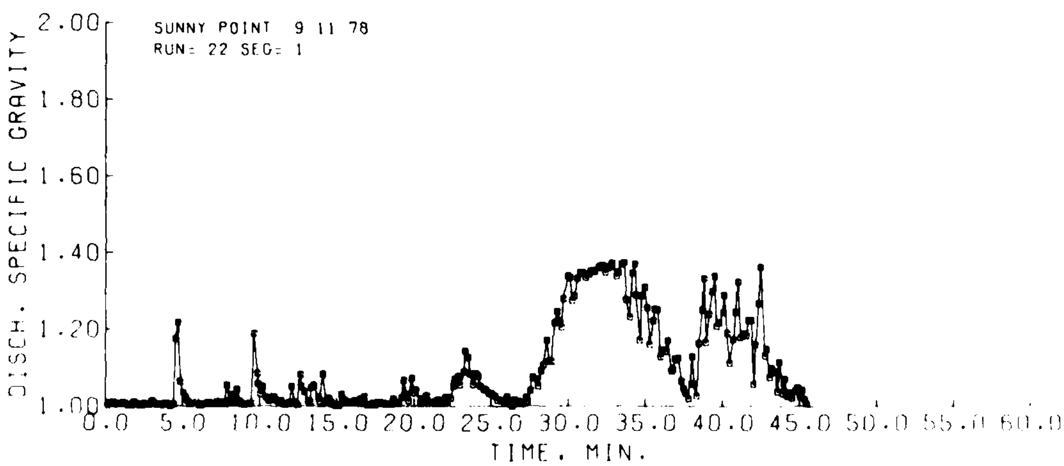
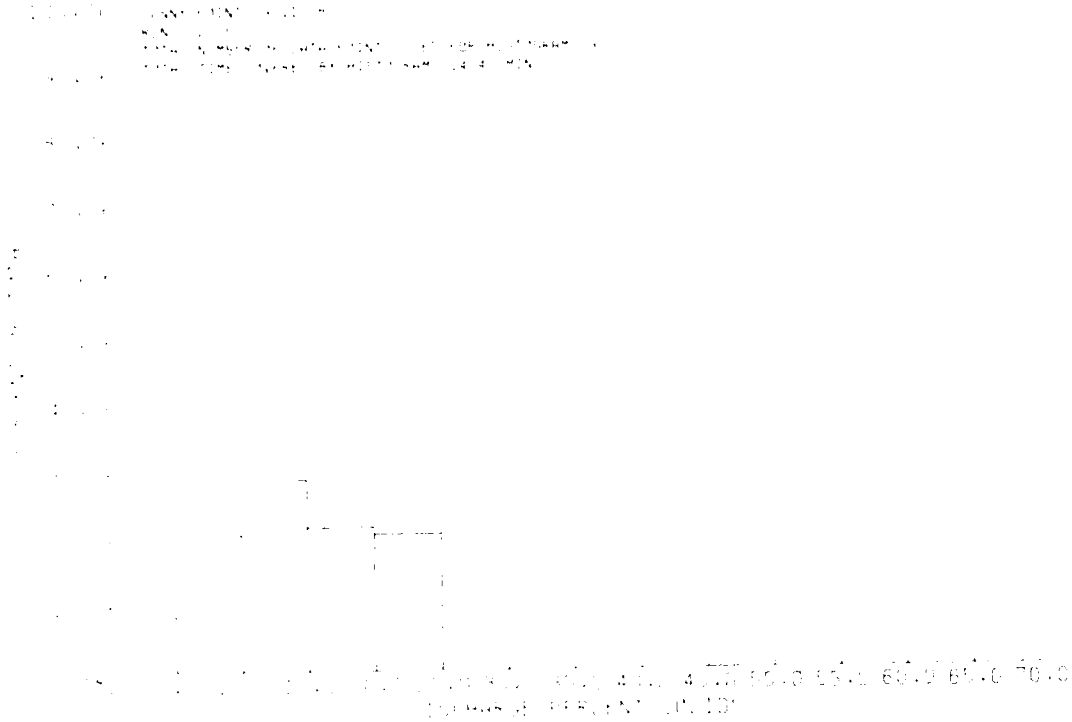

SUNNY POINT 9 11 78
RUN= 22 SEG= 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A64



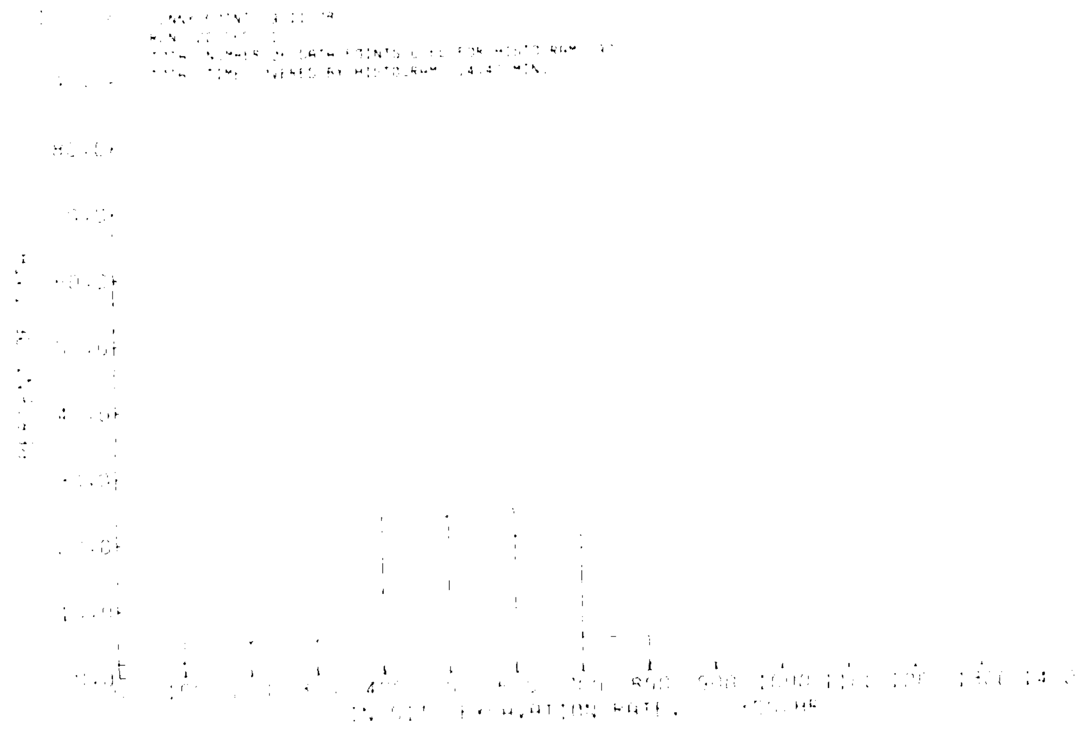
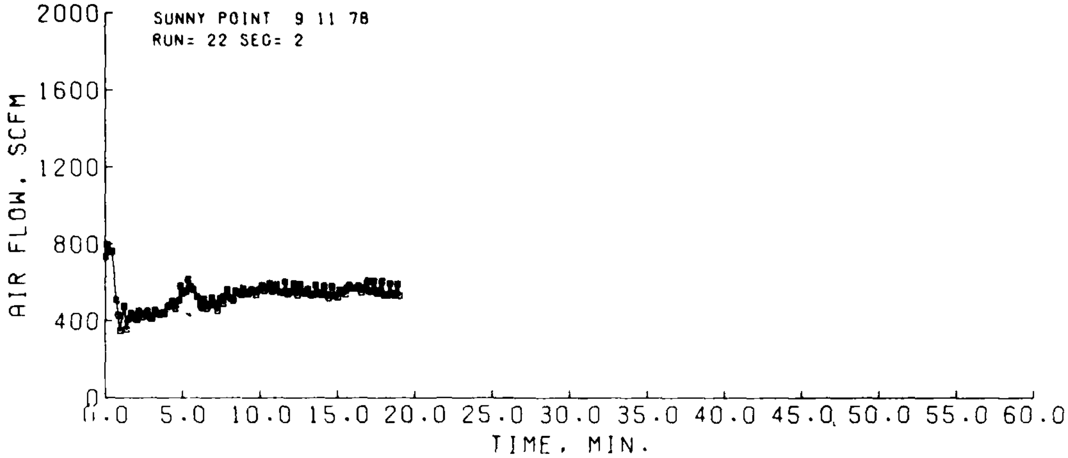
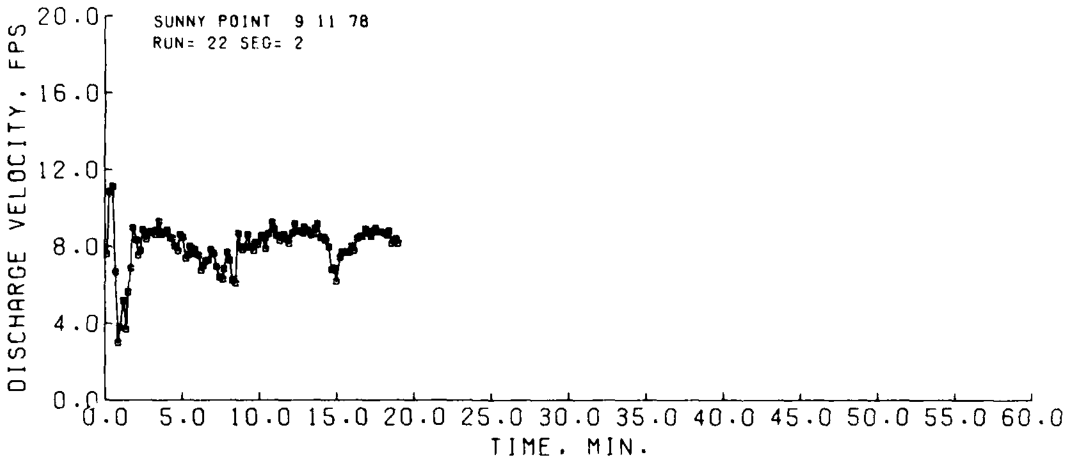


PLATE A65


SUNNY POINT 9 11 78
RUN= 22 SEG= 2
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 9 11 78
RUN= 22 SEG= 2
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

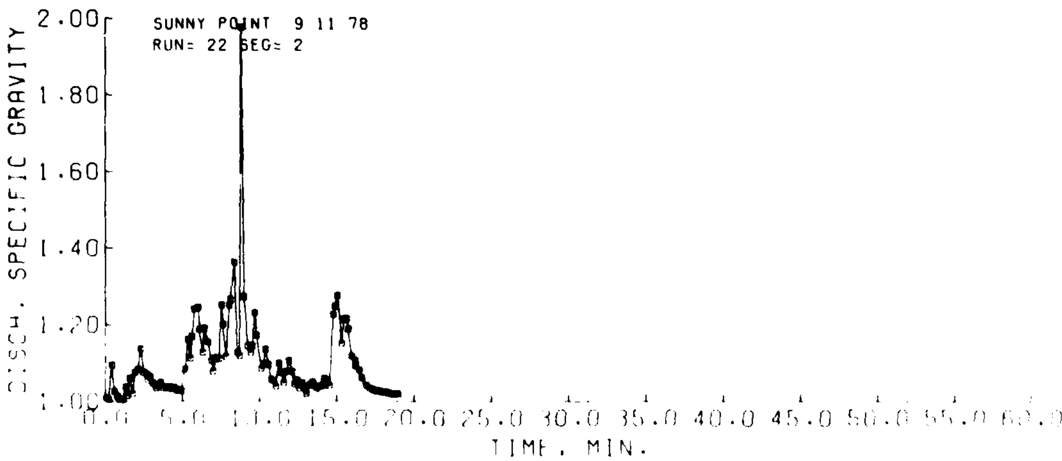
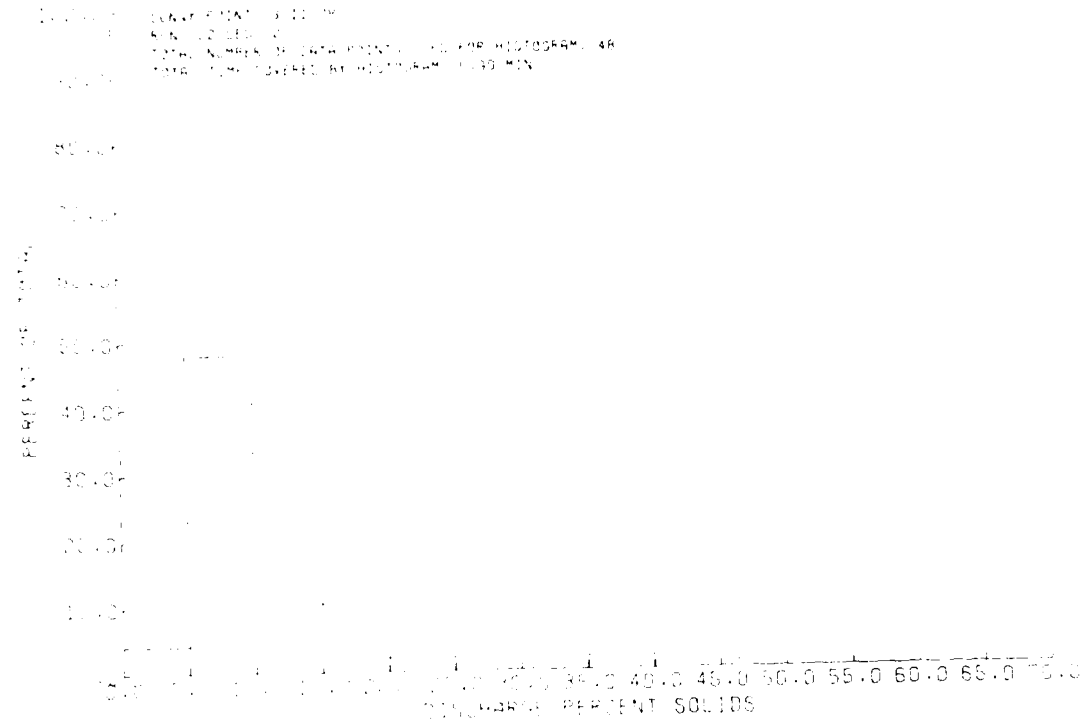

SUNNY POINT 9 11 78
RUN= 22 SEG= 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A66


80.0
40.0
30.0
40.0 45.0 50.0 55.0 60.0 65.0
PERCENT SOLIDS

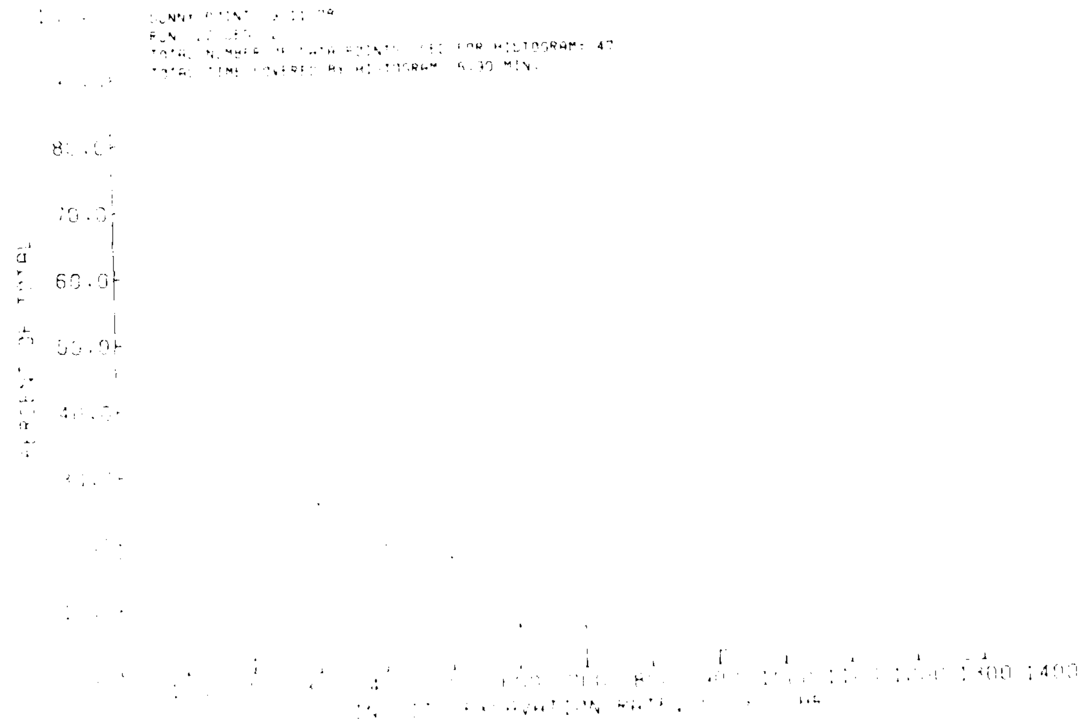
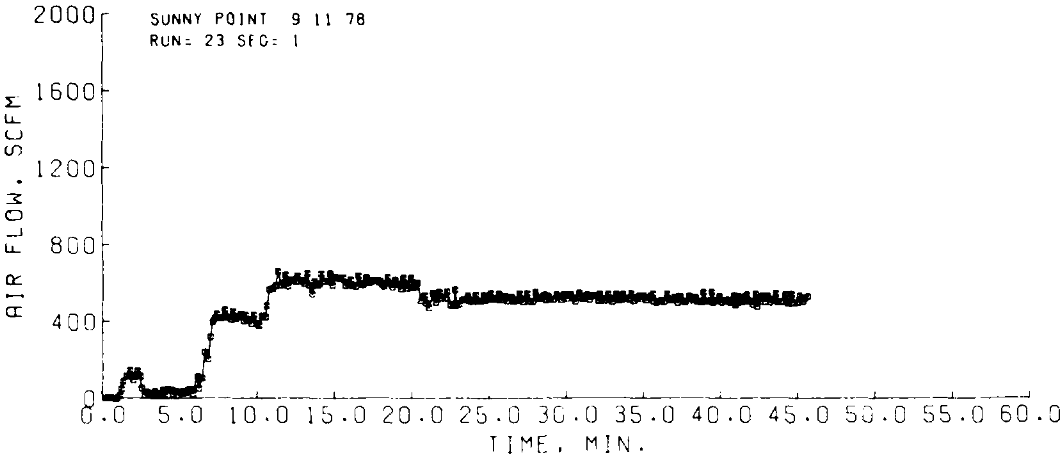
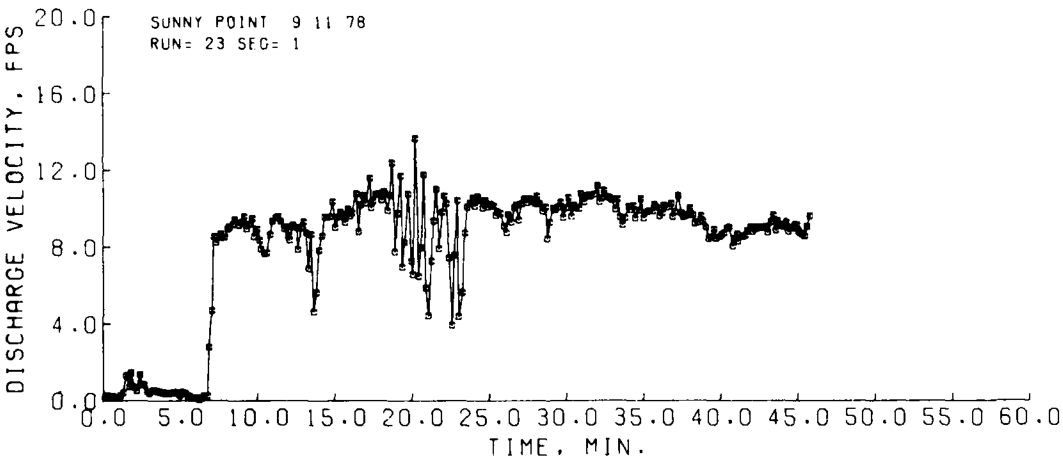

80.0
70.0
60.0
50.0
1400

PLATE A67


SUNNY POINT 9 11 78
RUN= 23 SEG= 1
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 9 11 78
RUN= 23 SEG= 1
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

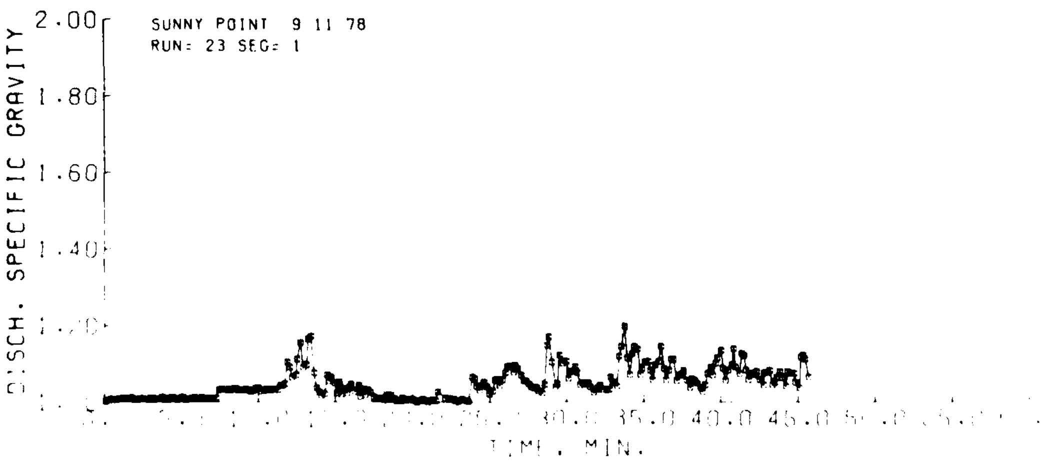
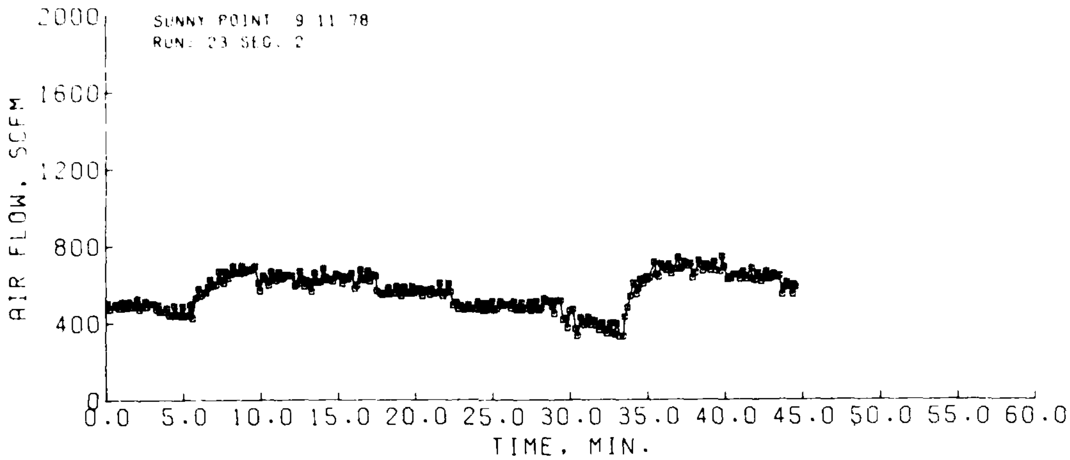
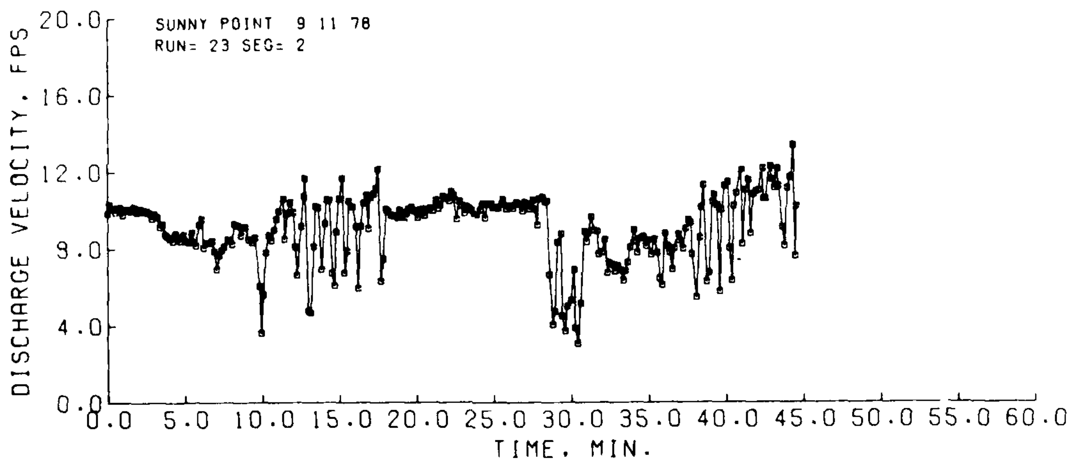

SUNNY POINT 9 11 78
RUN= 23 SEG= 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
TIME, MIN.

PLATE A68


SUNNY POINT 9 11 78
RUN= 23 SEG= 2
AIR FLOW, SCFM
TIME, MIN.


SUNNY POINT 9 11 78
RUN= 23 SEG= 2
DISCHARGE VELOCITY, FPS
TIME, MIN.

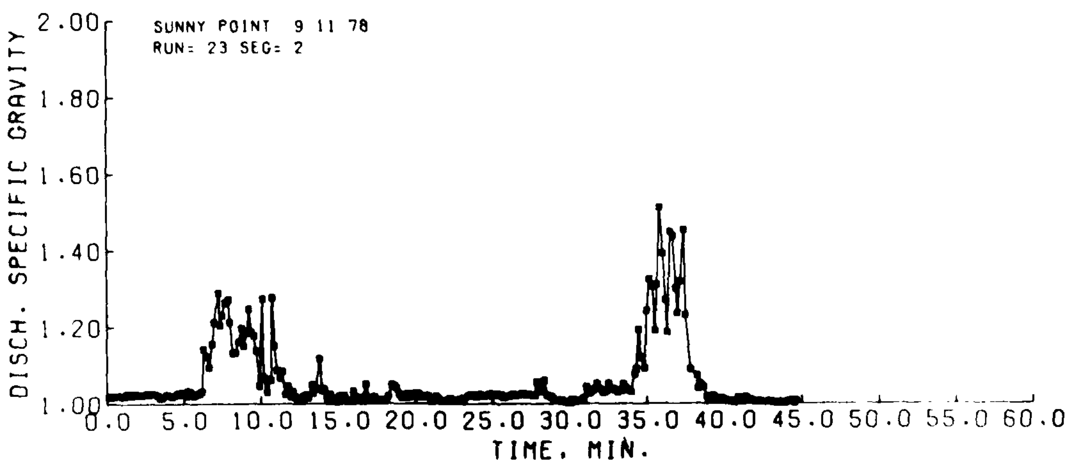
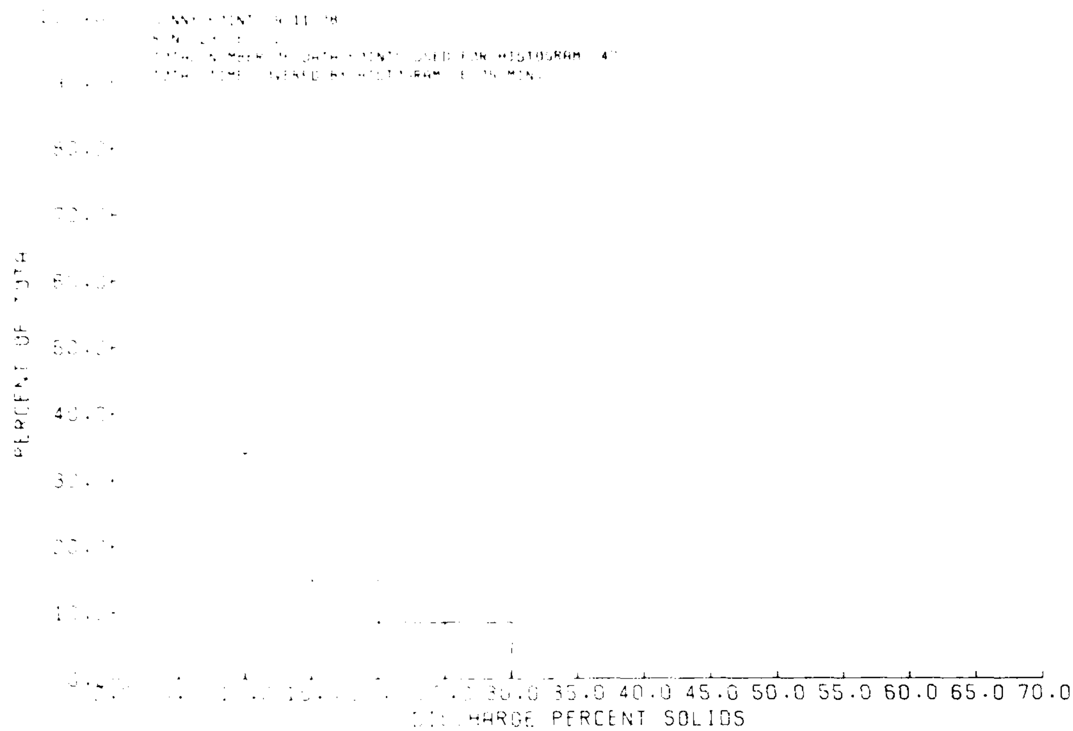
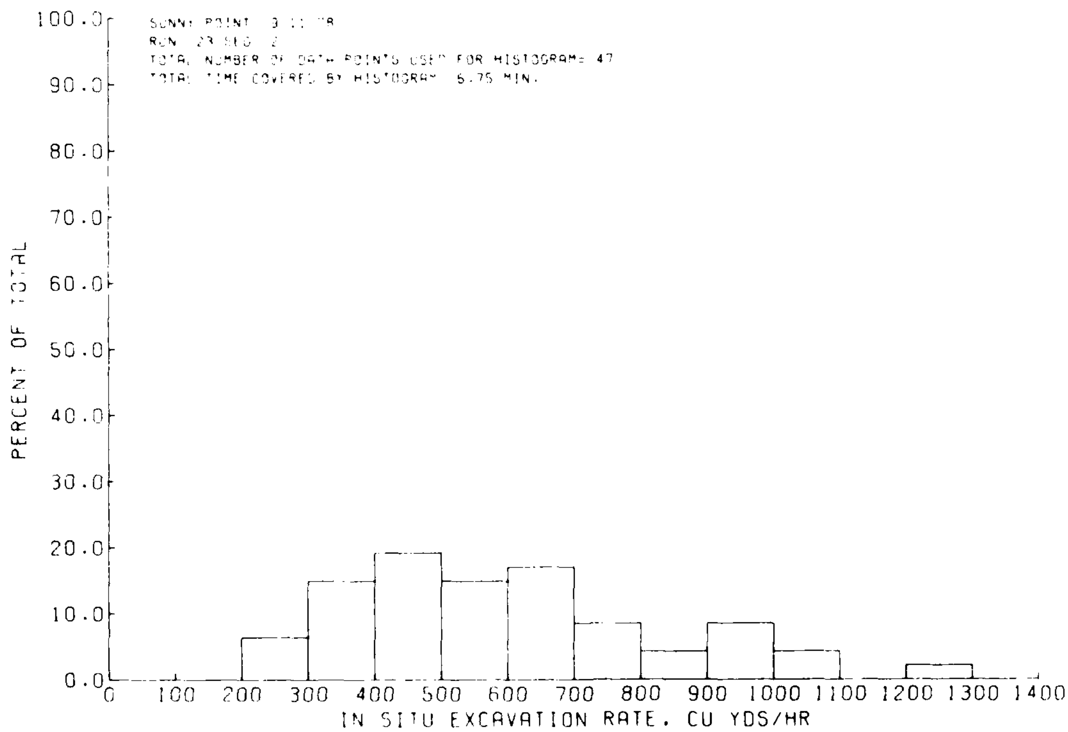

SUNNY POINT 9 11 78
RUN= 23 SEG= 2
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A69

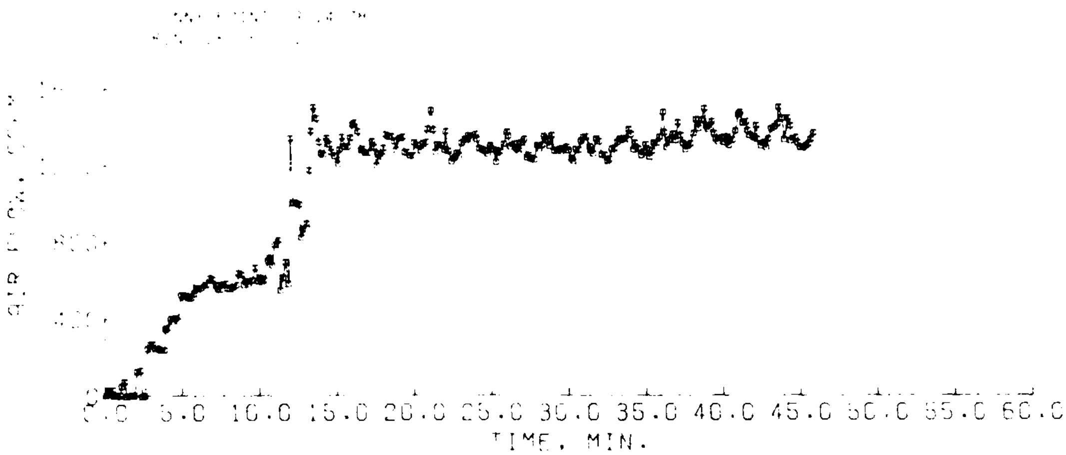


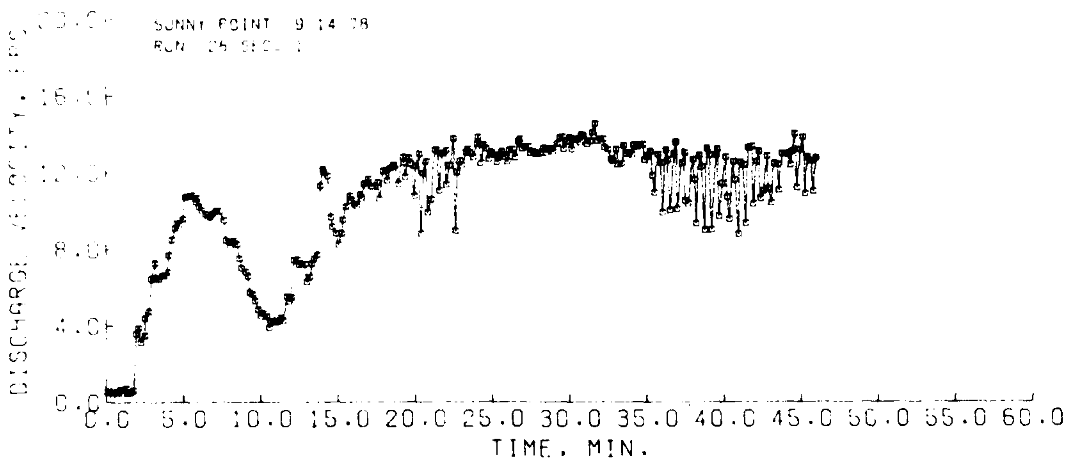
30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
HARGE PERCENT SOLIDS



TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 47
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
PERCENT OF TOTAL
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
IN SITU EXCAVATION RATE, CU YDS/HR

PLATE A70


AIR FLOW, CFM
800
400
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 9 14 78
RUN 26 SEC 1
DISCHARGE VELOCITY, FPS
16.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

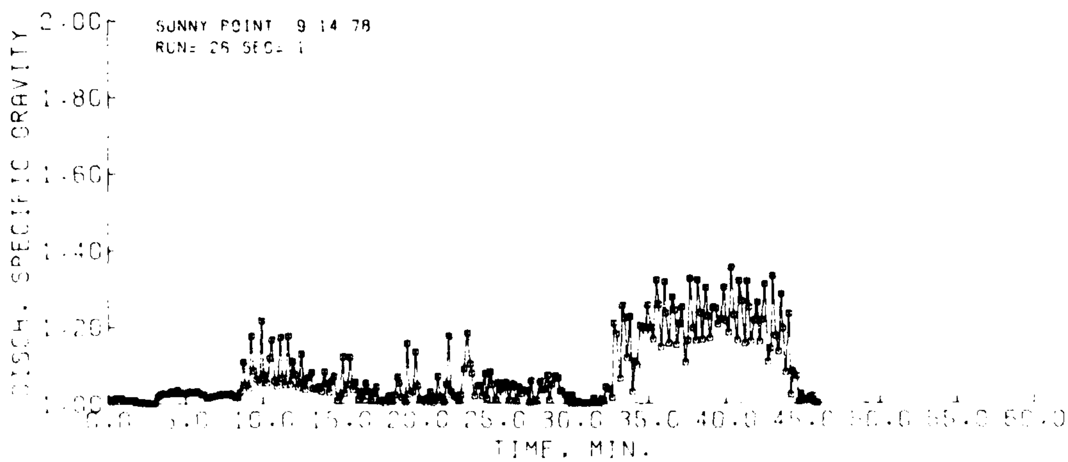

SUNNY POINT 9 14 78
RUN 26 SEC 1
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A71

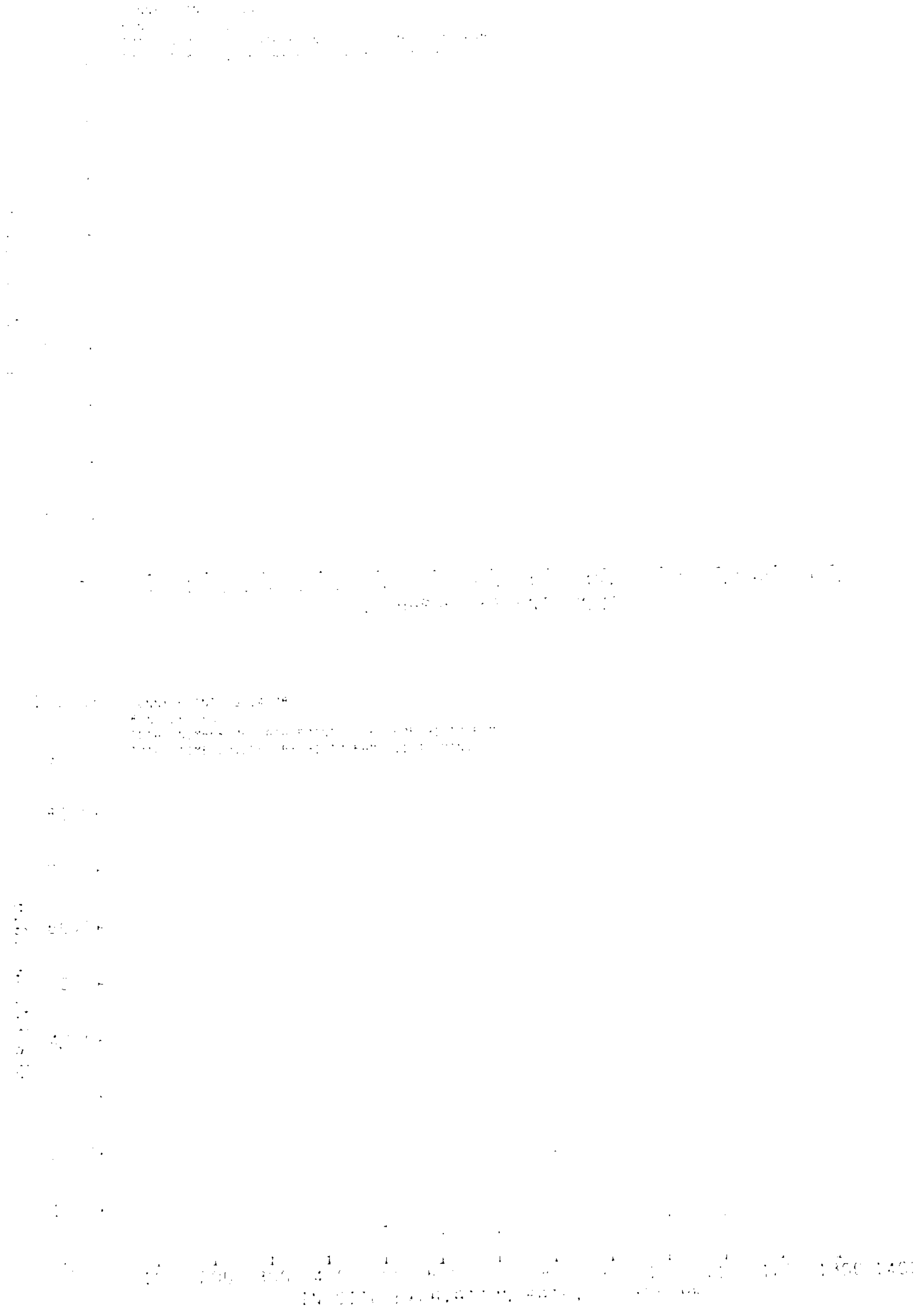
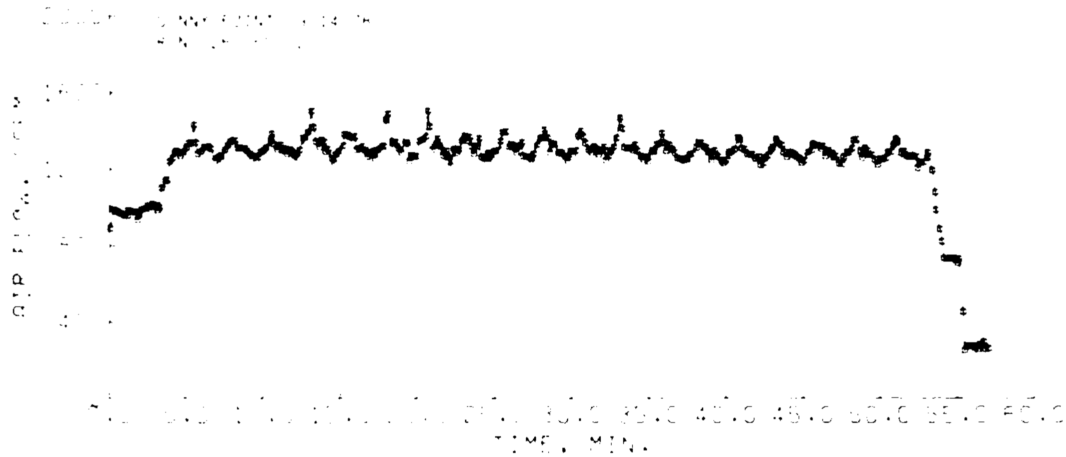
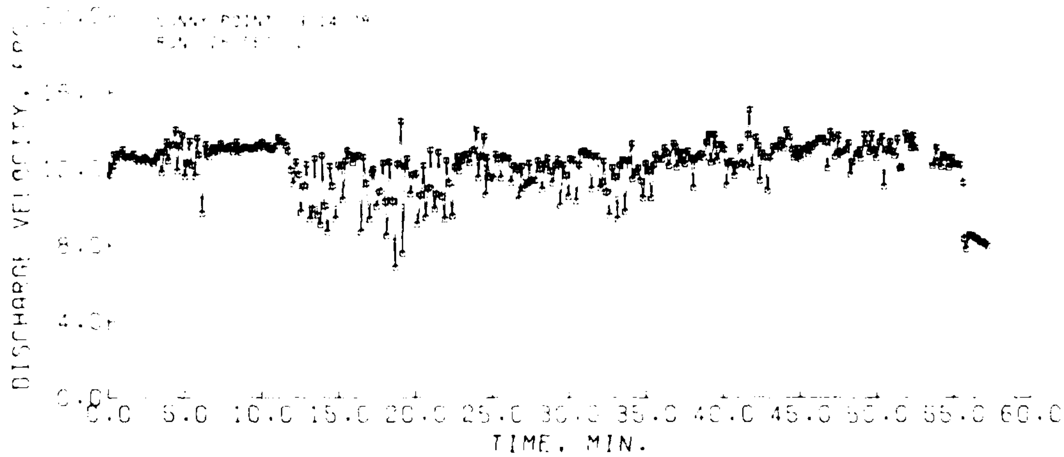


PLATE A72


TIME, MIN.


DISCHARGE VELOCITY
0.0
4.0
8.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

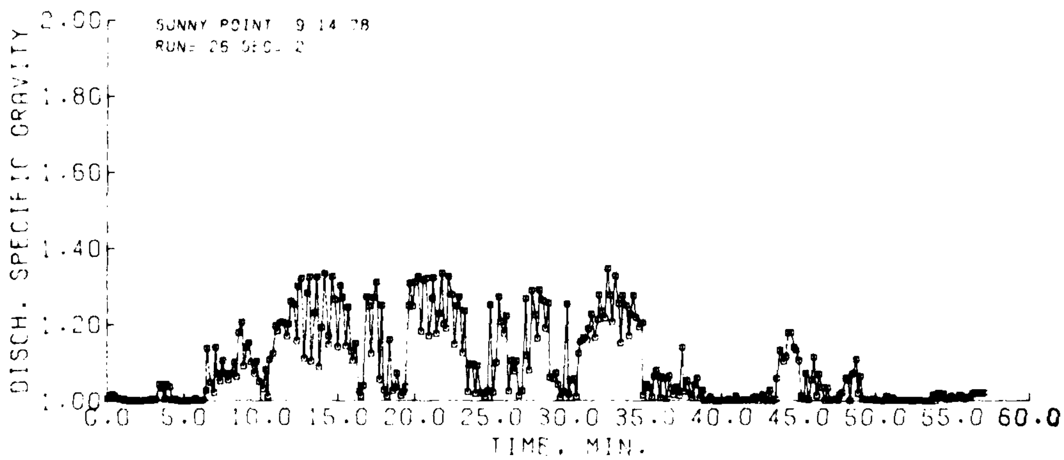
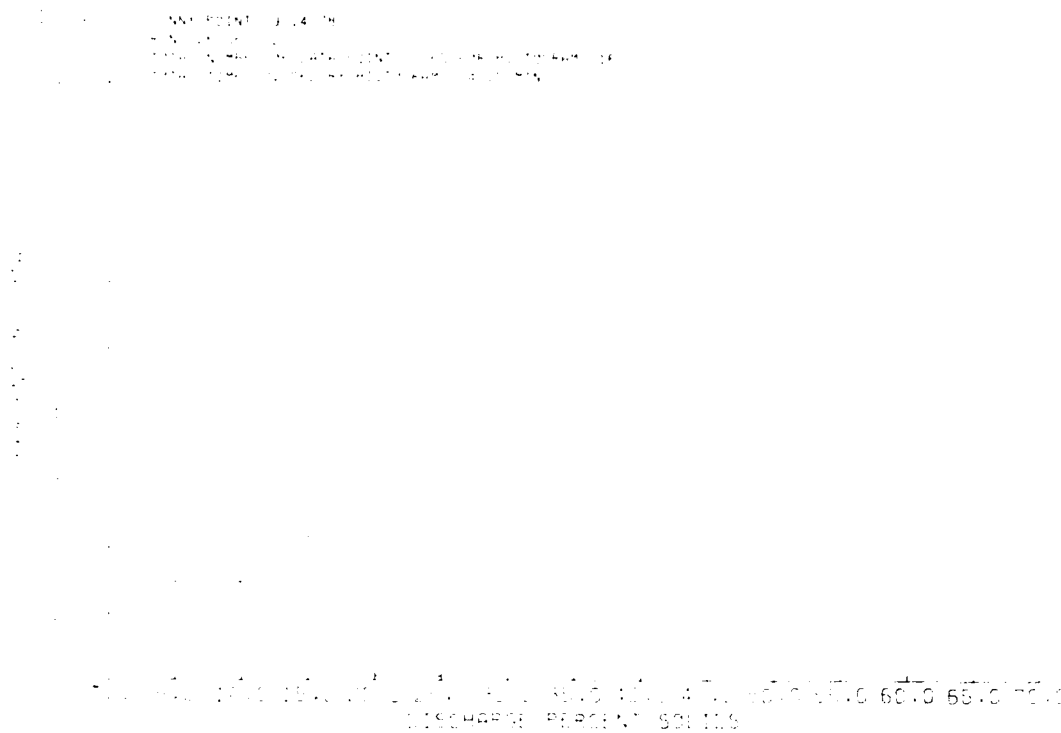

SUNNY POINT 9 14 78
RUN= 26 SEC. 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A73


60.0 65.0
DISCHARGE PERCENT SOLIDS

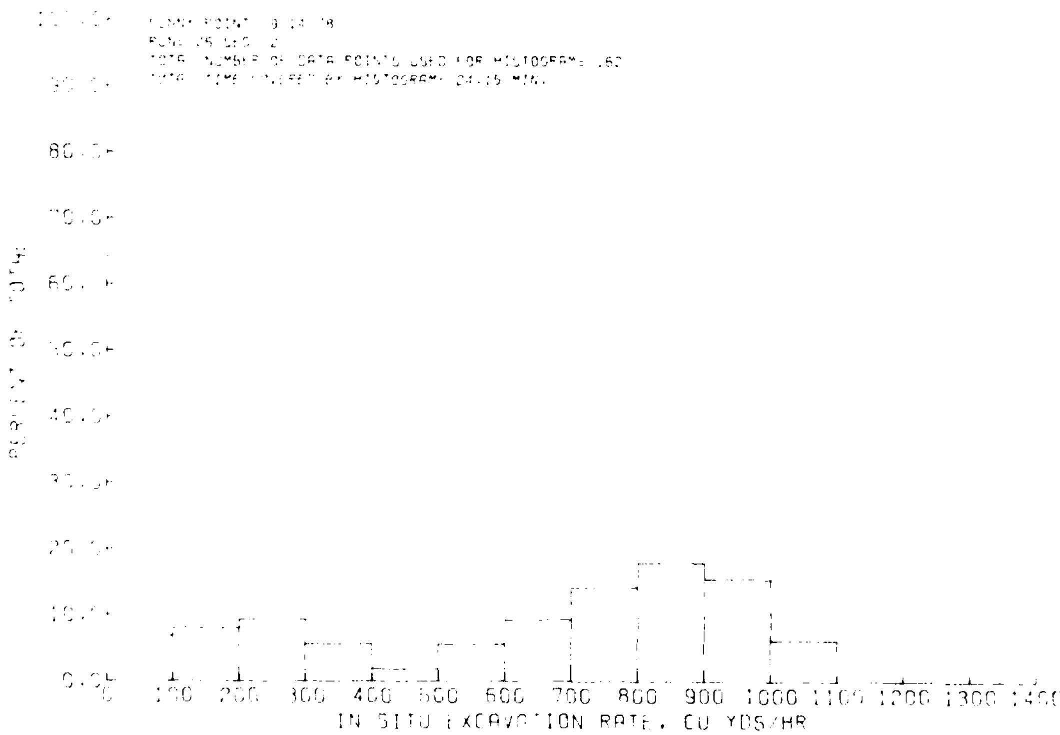
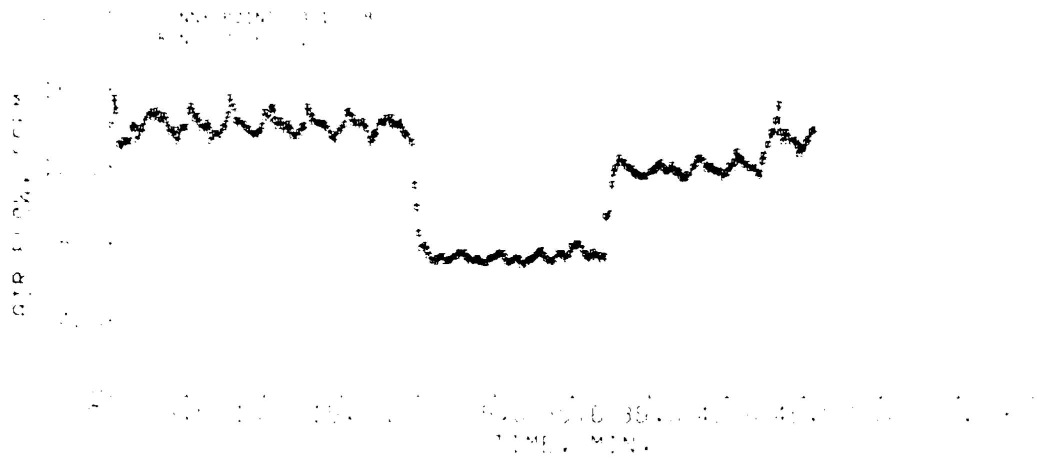

TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM
80.0
70.0
0.0
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
IN SITU EXCAVATION RATE, CU YDS/HR

PLATE A74


TIME, MIN.


SUNNY POINT
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0
TIME, MIN.

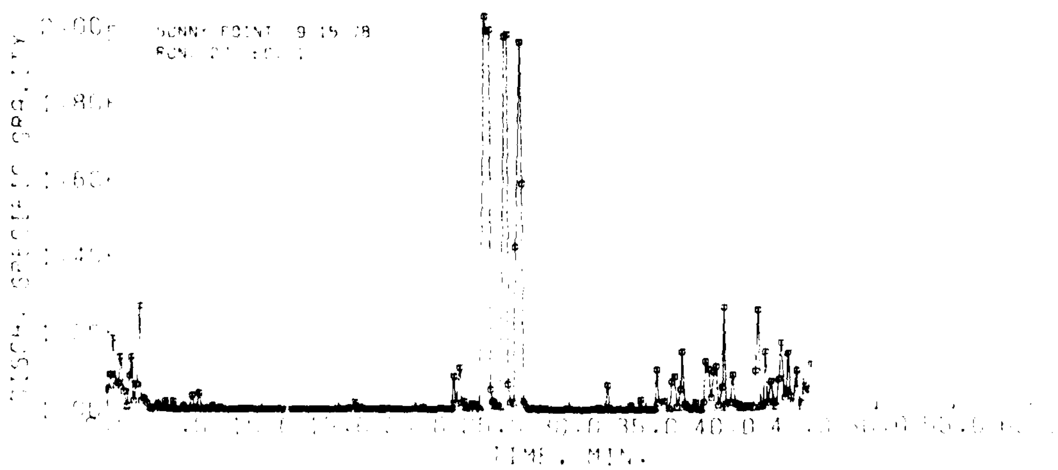
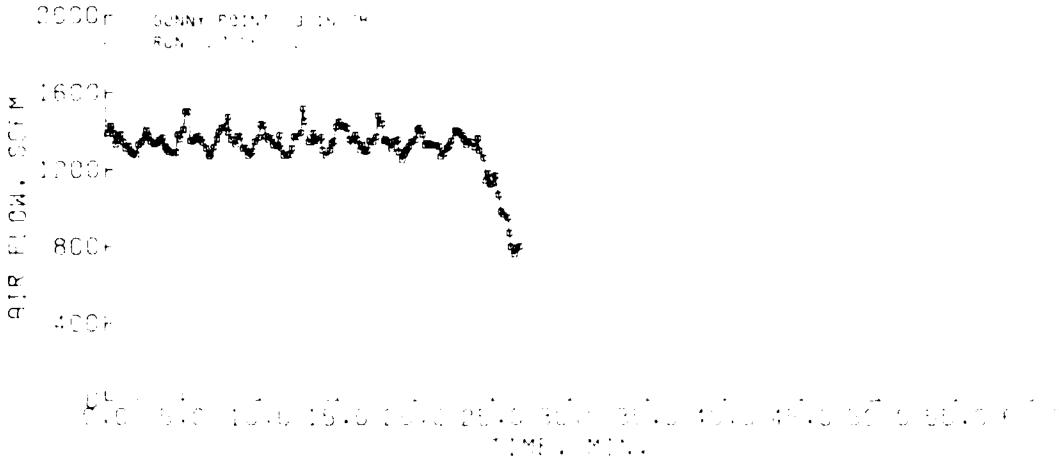
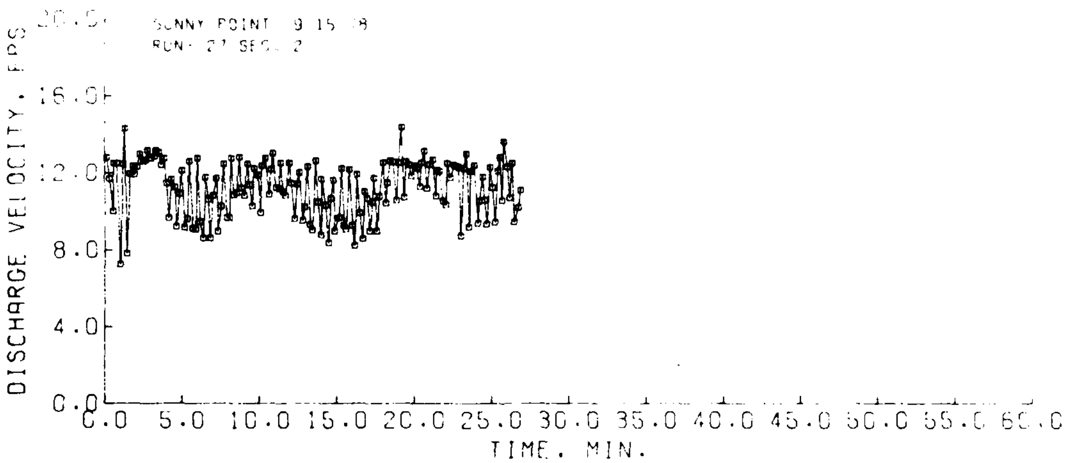

SUNNY POINT 9 15 78
TIME, MIN.

PLATE A75


SUNNY POINT 9 15 78
AIR FLOW, SCFM
TIME, MIN.


SUNNY POINT 9 15 78
RUN= 27 SEG= 2
DISCHARGE VELOCITY, FPS
0.0
4.0
8.0
12.0
16.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

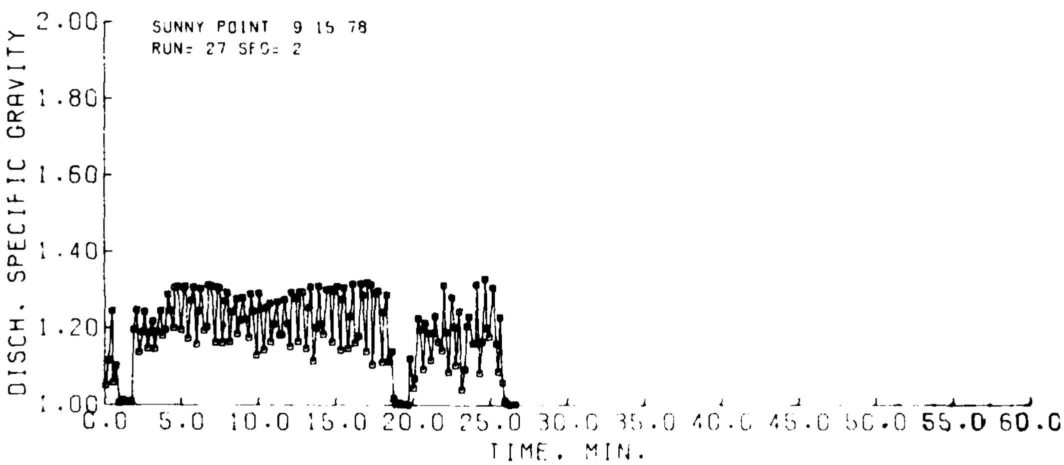
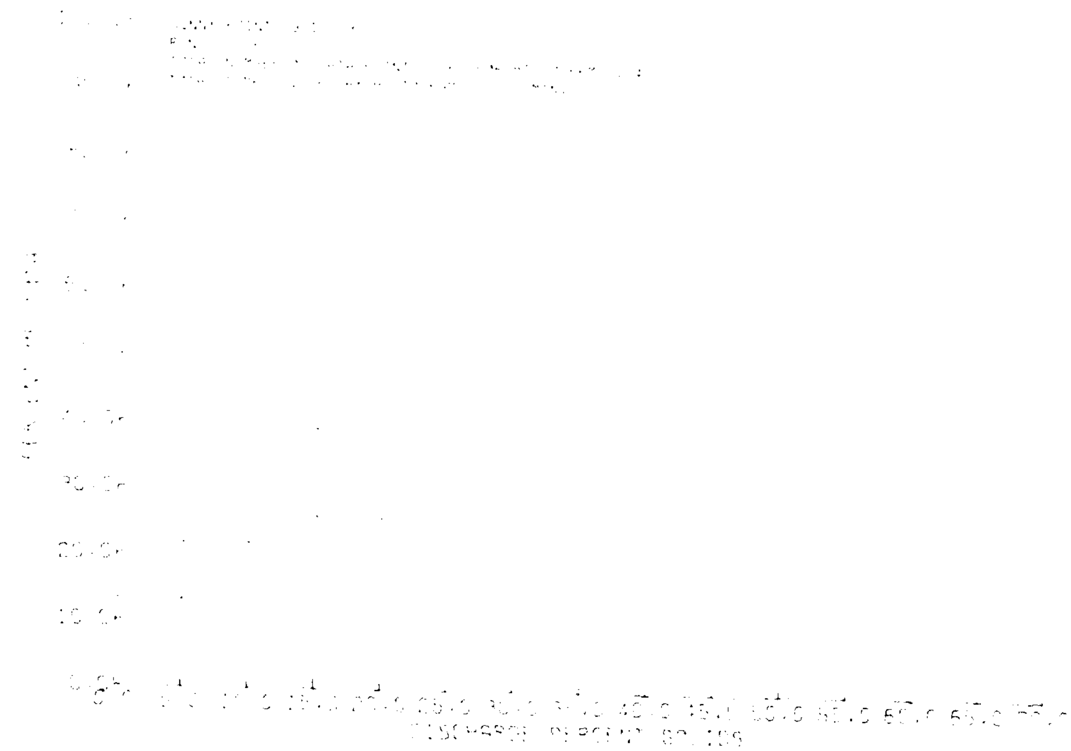

SUNNY POINT 9 15 78
RUN= 27 SEG= 2
DISCH. SPECIFIC GRAVITY
1.00
1.20
1.40
1.60
1.80
2.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A76



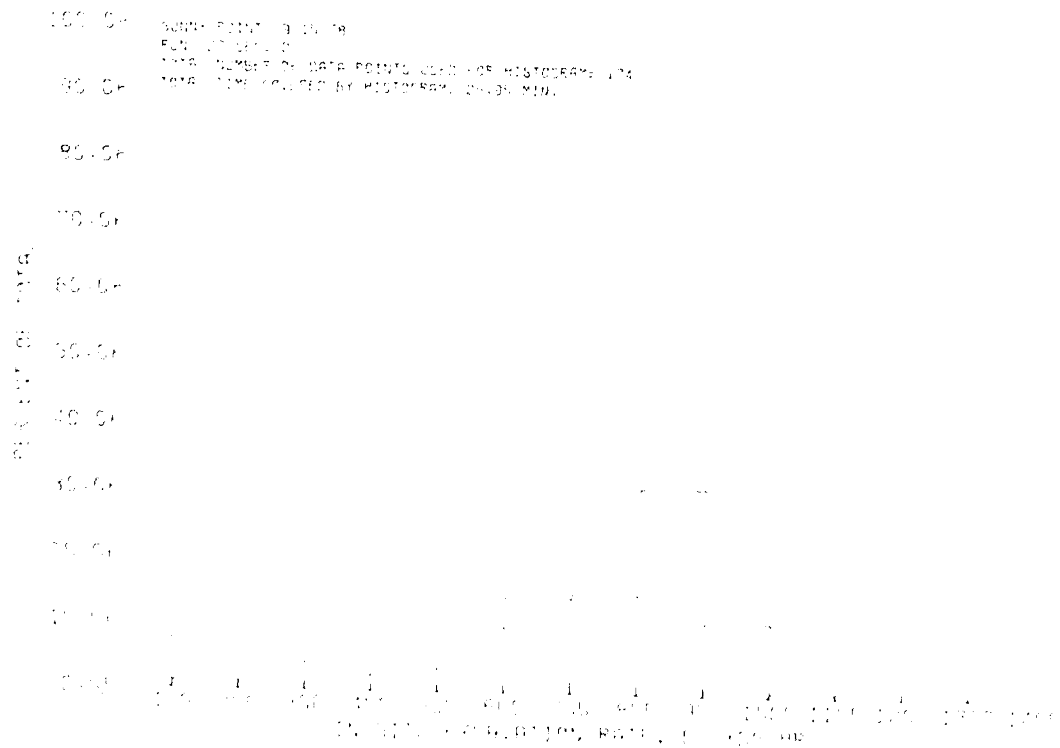
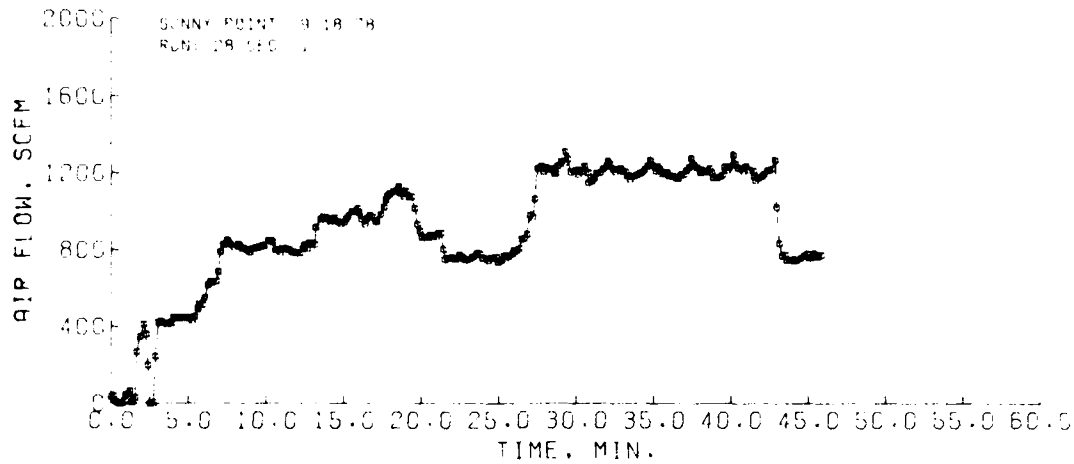
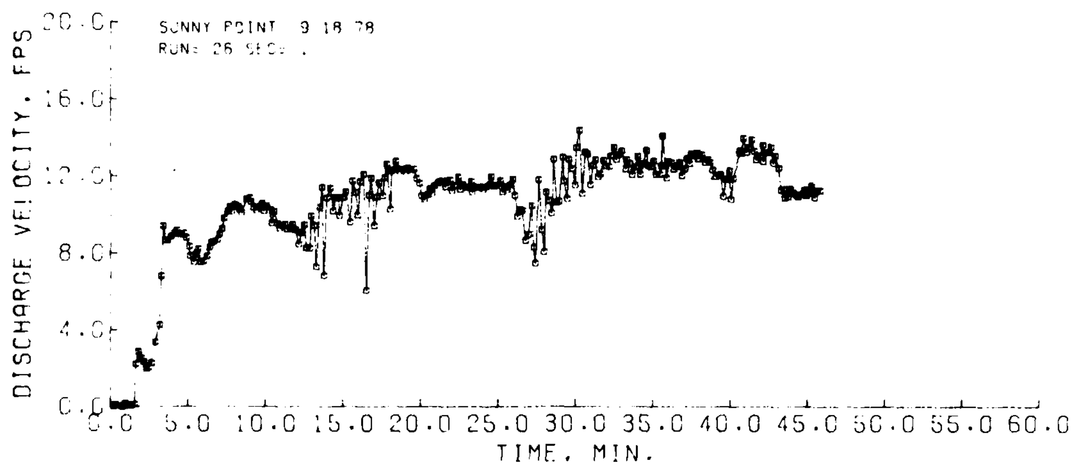


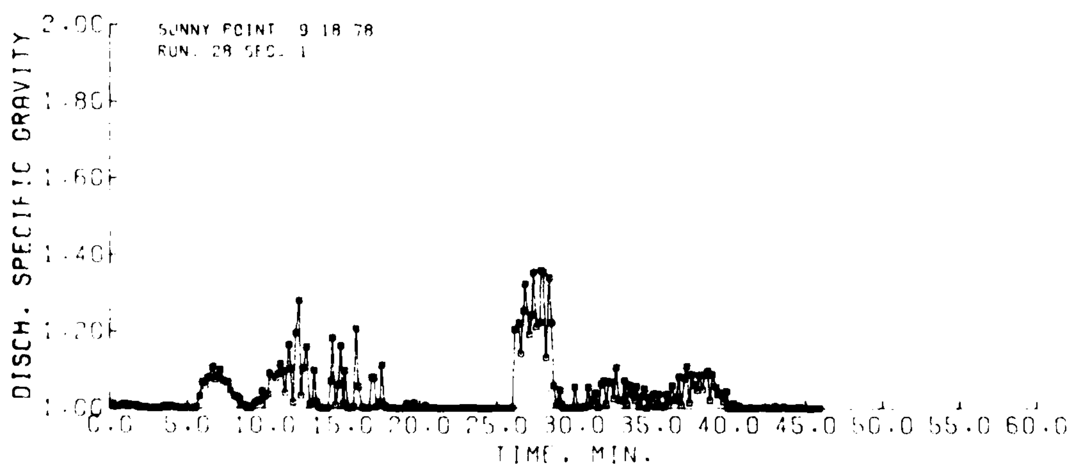
PLATE A77



SUNNY POINT 9 18 78
RUN: 28 SEC. 1
AIR FLOW, SCFM
TIME, MIN.

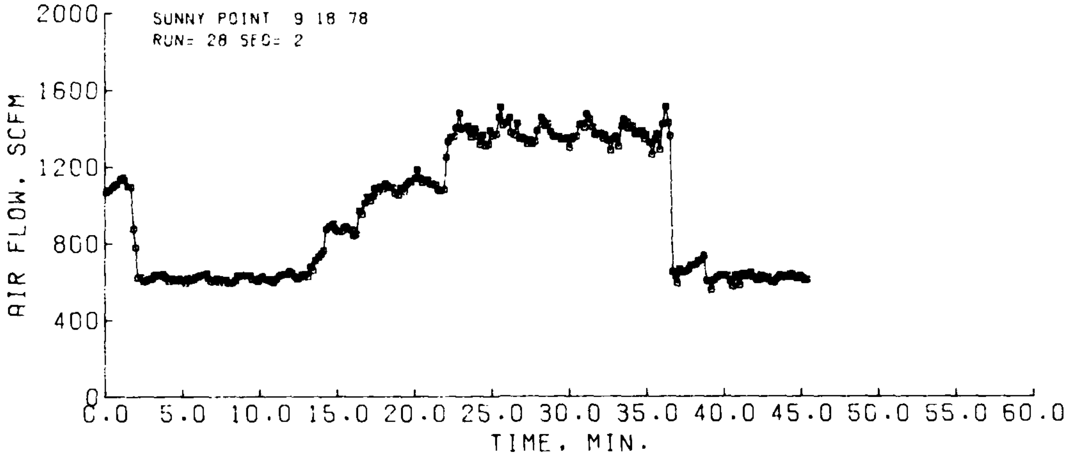


SUNNY POINT 9 18 78
RUN: 28 SEC. 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

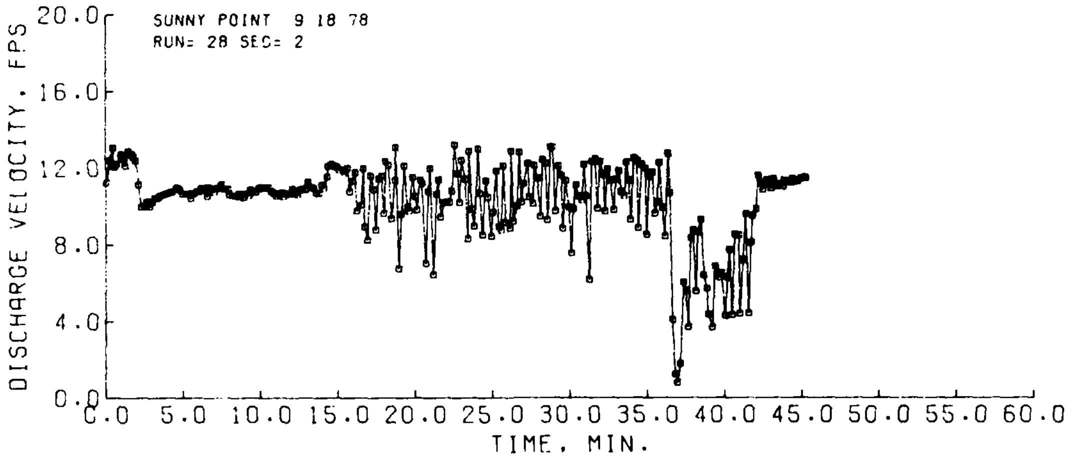


SUNNY POINT 9 18 78
RUN: 28 SEC. 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

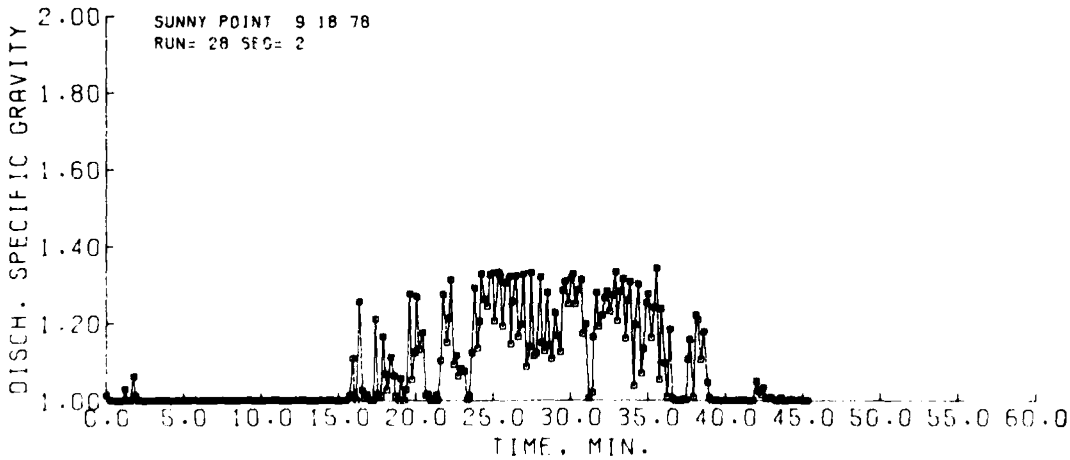
PLATE A78



SUNNY POINT 9 18 78
RUN= 28 SEC= 2
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

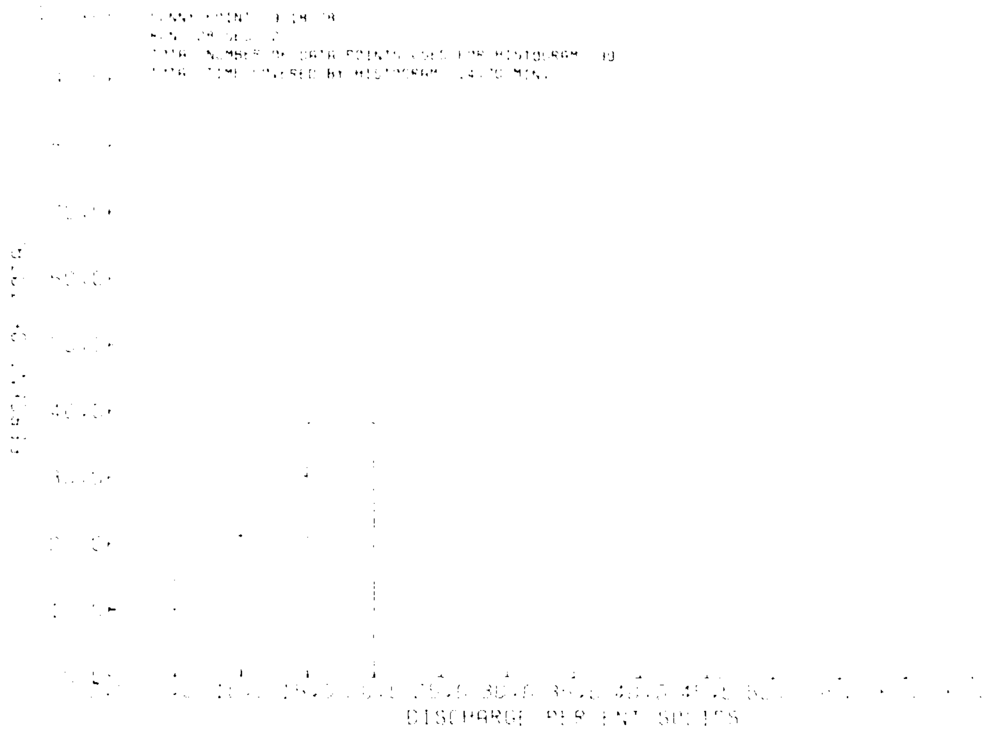


SUNNY POINT 9 18 78
RUN= 28 SEC= 2
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.



SUNNY POINT 9 18 78
RUN= 28 SEC= 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A79



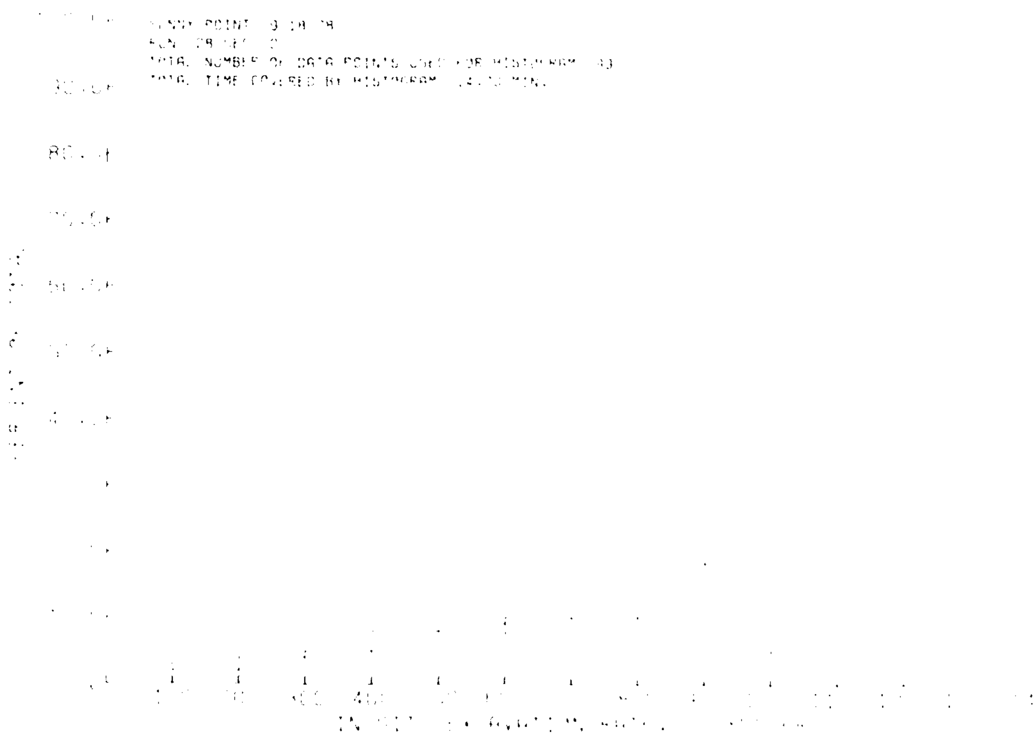
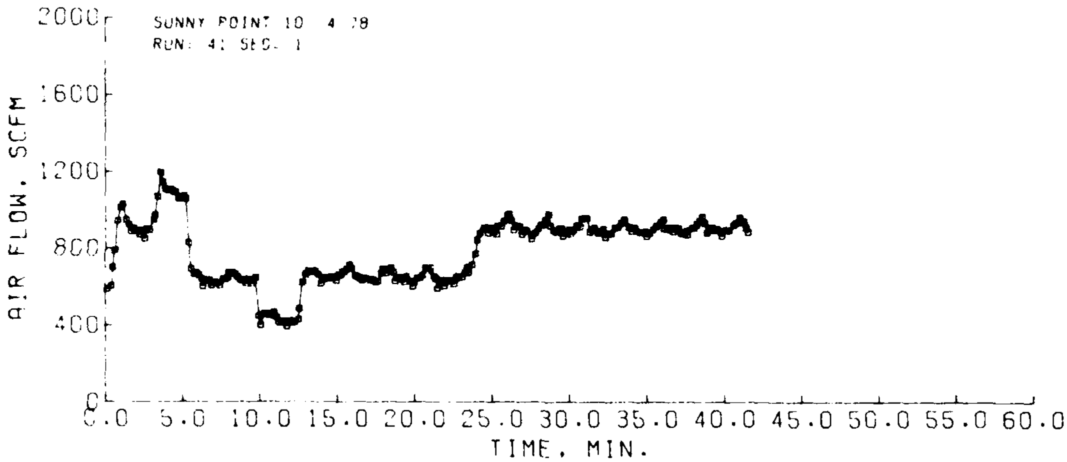
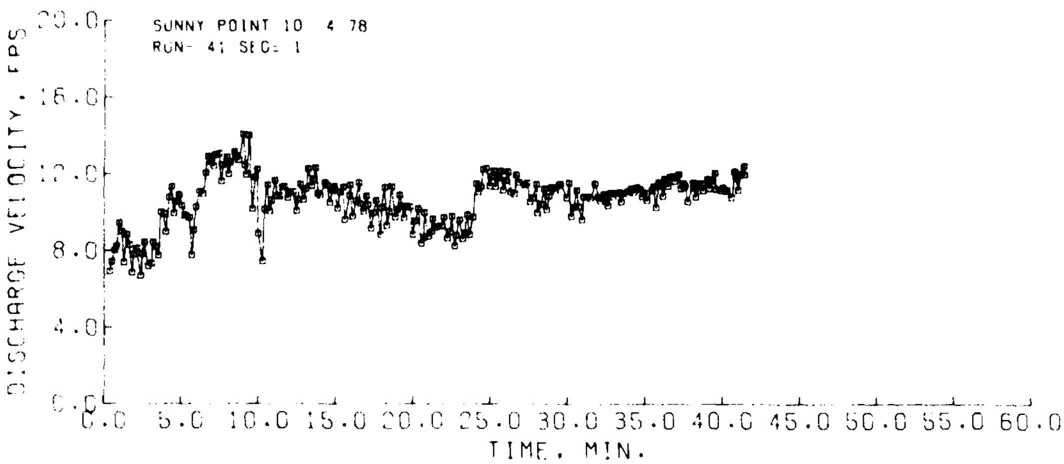


PLATE A80


SUNNY POINT 10 4 78
RUN: 41 SEG: 1
AIR FLOW, SCFM
TIME, MIN.


SUNNY POINT 10 4 78
RUN- 41 SEG: 1
DISCHARGE VELOCITY, FPS
TIME, MIN.

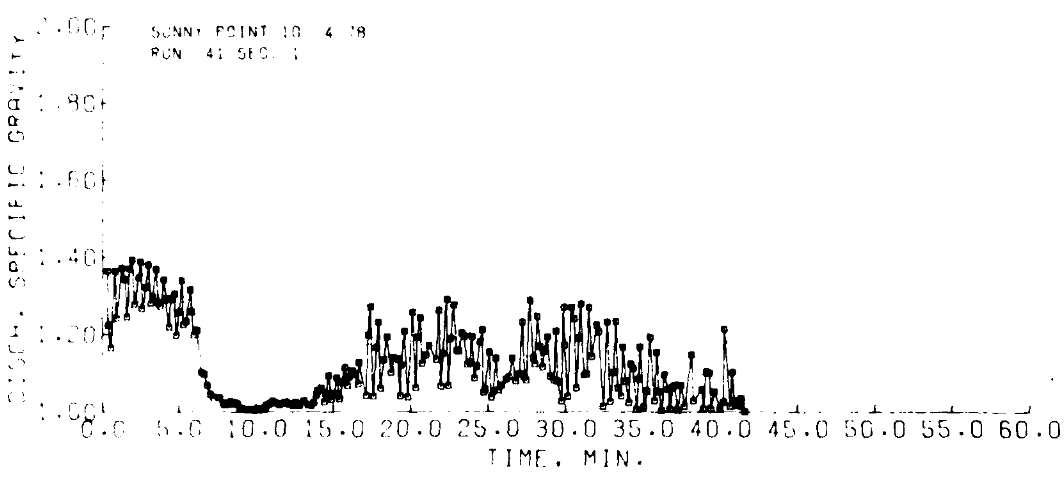
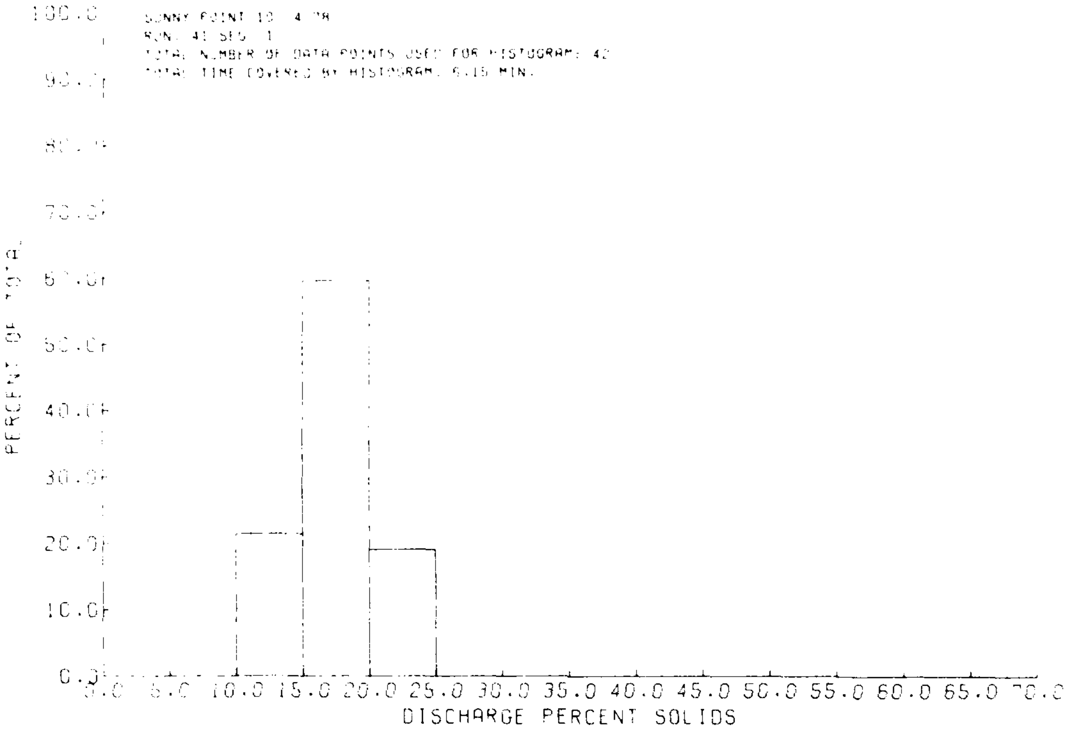

SUNNY POINT 10 4 78
RUN 41 SEG. 1
TIME, MIN.

PLATE A81


SUNNY POINT 10 4 78
RUN 41 SEG 1
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 42
TOTAL TIME COVERED BY HISTOGRAM= 6.15 MIN.
PERCENT OF TOTAL
DISCHARGE PERCENT SOLIDS

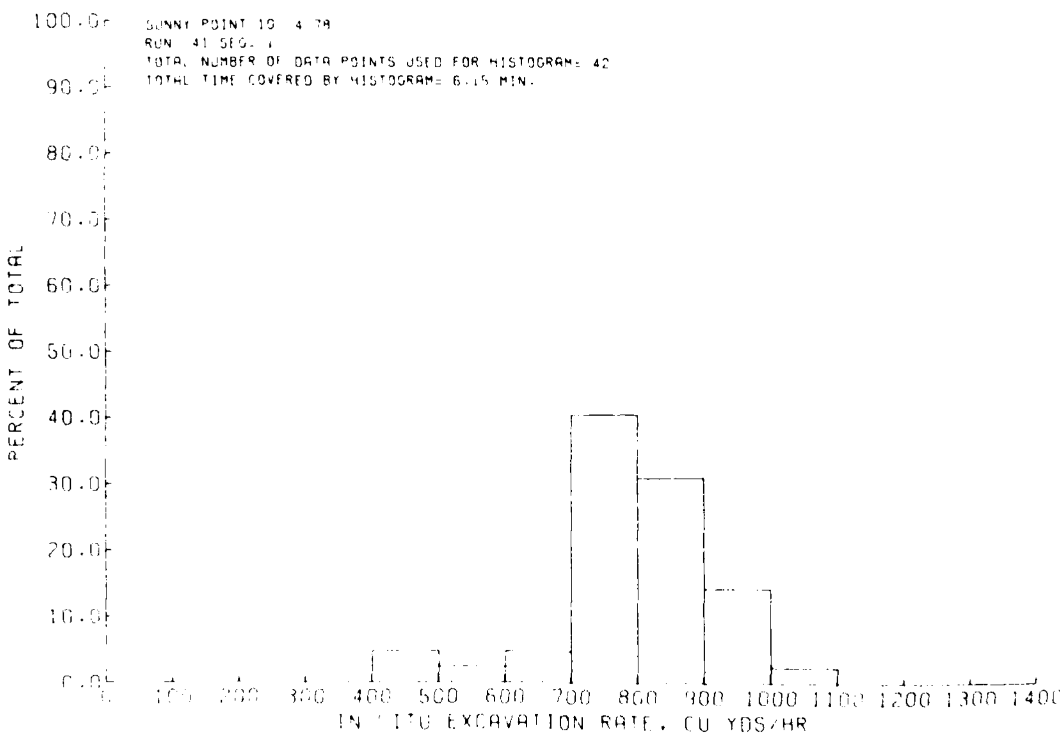
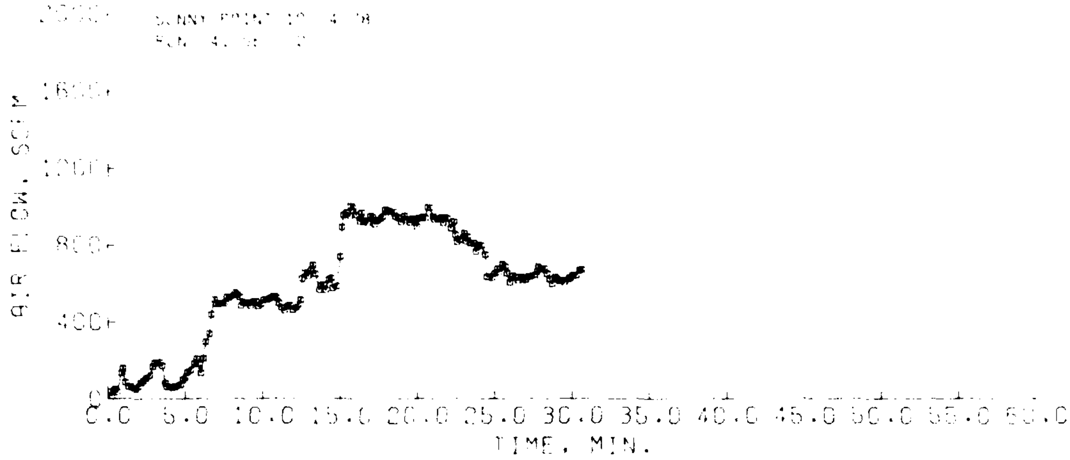
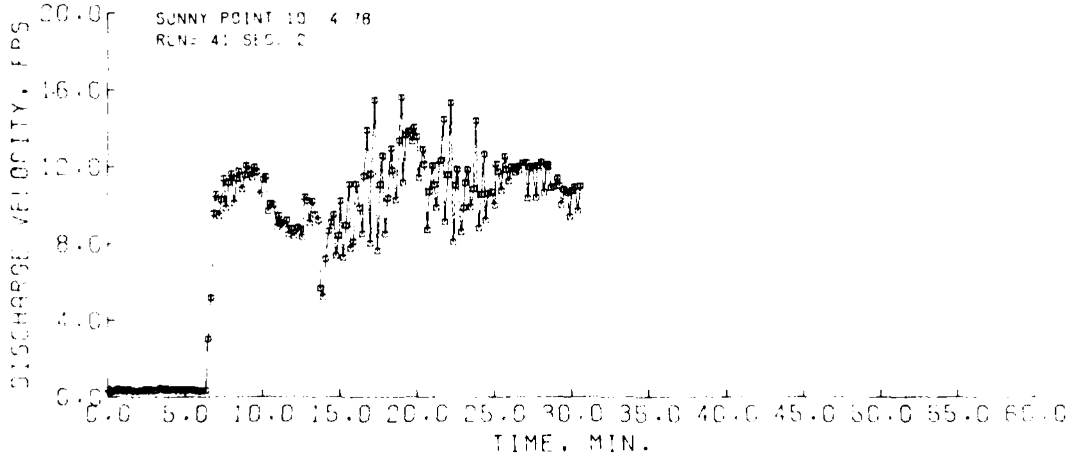

SUNNY POINT 10 4 78
RUN 41 SEG 1
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 42
TOTAL TIME COVERED BY HISTOGRAM= 6.15 MIN.
PERCENT OF TOTAL
IN SITU EXCAVATION RATE, CU YDS/HR

PLATE A82


SUNNY POINT 10 4 78
RUN 41 SEC 2
AIR FLOW, SCFM
TIME, MIN.


SUNNY POINT 10 4 78
RUN: 41 SEC. 2
DISCHARGE VELOCITY, FPS
TIME, MIN.

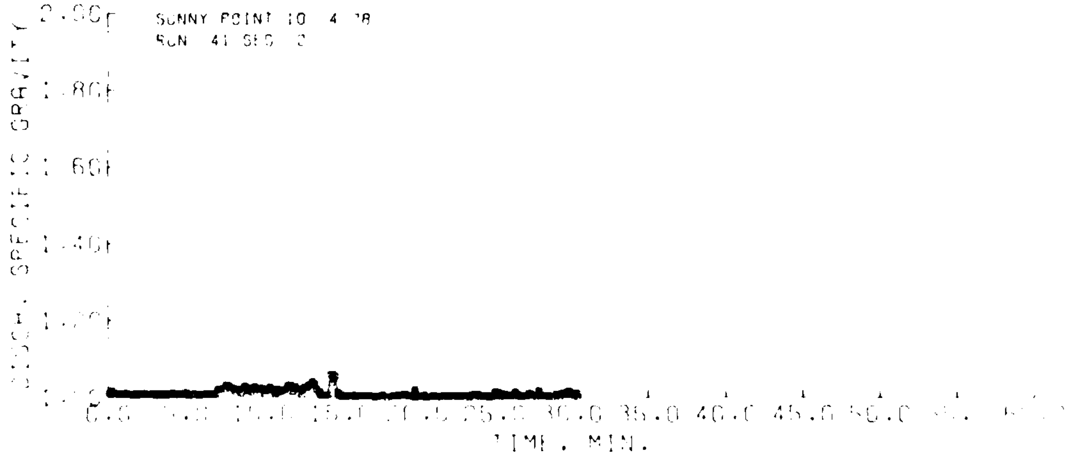
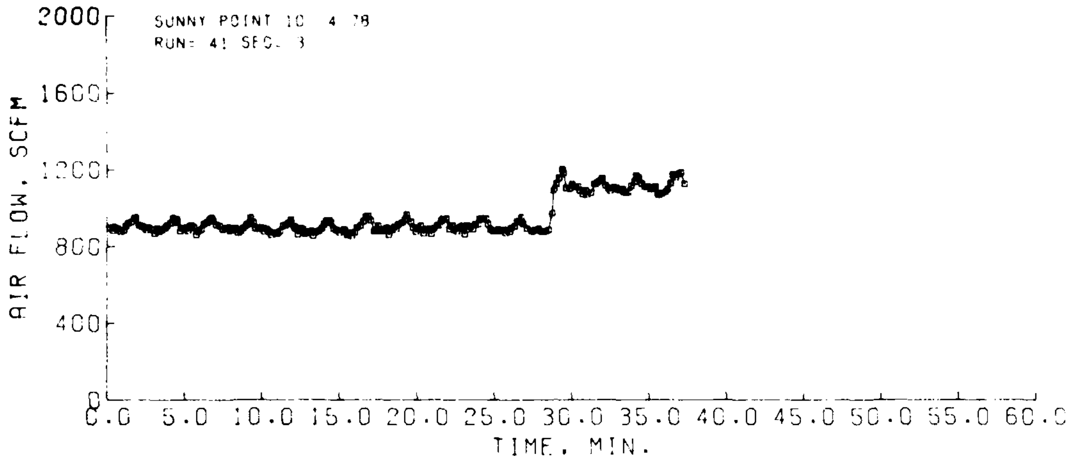
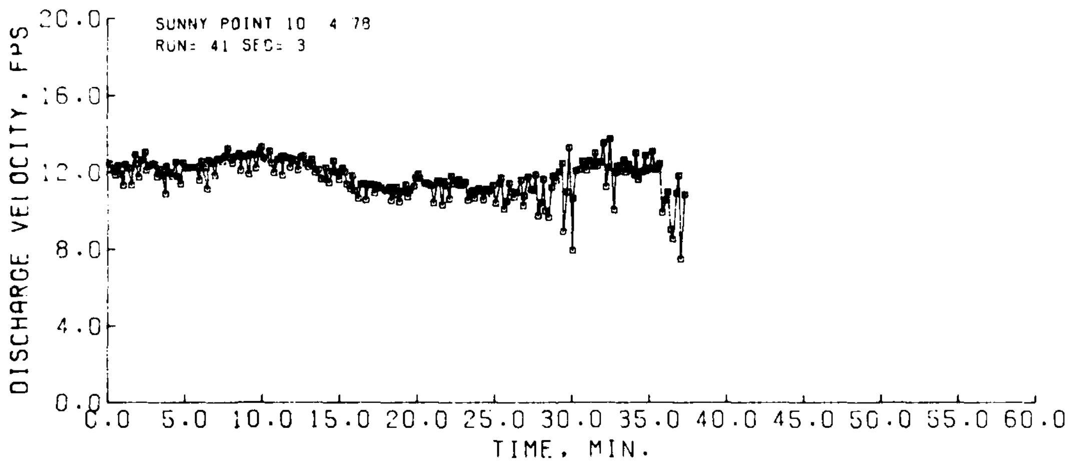

SUNNY POINT 10 4 78
RUN 41 SEC 2
TIME, MIN.

PLATE A83


SUNNY POINT 10 4 78
RUN= 41 SEC= 3
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 10 4 78
RUN= 41 SEC= 3
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

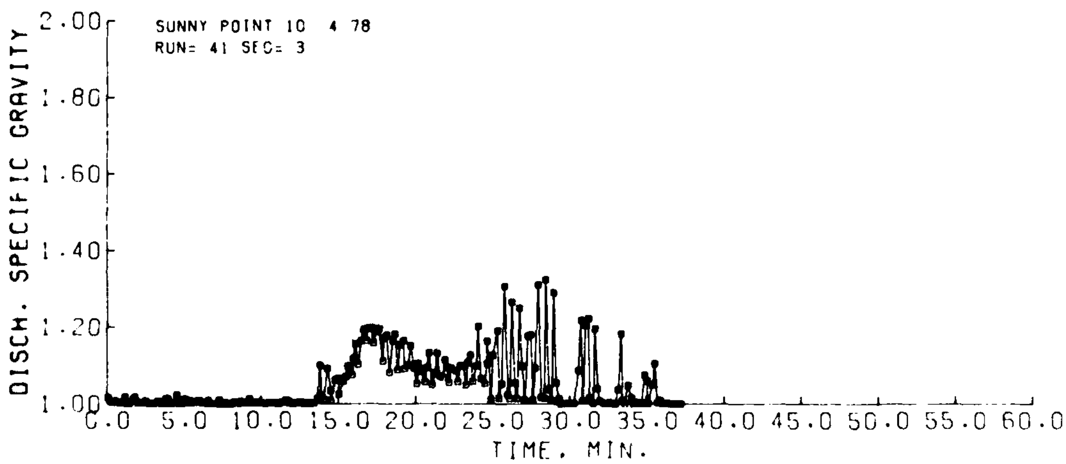

SUNNY POINT 10 4 78
RUN= 41 SEC= 3
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A84

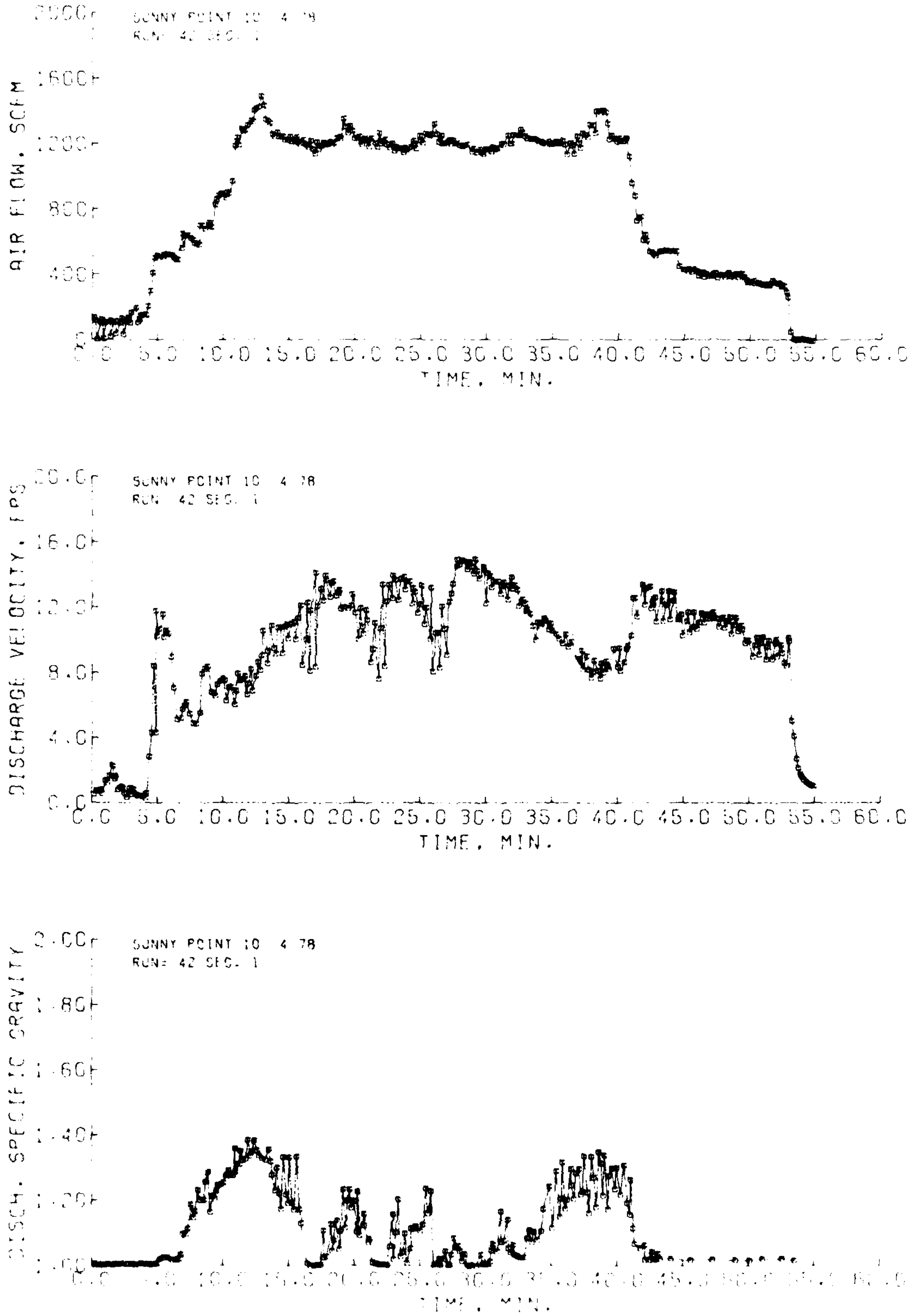

SUNNY POINT 10 4 78
RUN 42 SEG. 1
AIR FLOW, SCFM
TIME, MIN.
SUNNY POINT 10 4 78
RUN 42 SEG. 1
DISCHARGE VELOCITY, FPS
TIME, MIN.
SUNNY POINT 10 4 78
RUN 42 SEG. 1
DISCH. SPECIFIC GRAVITY
TIME, MIN.

PLATE A85

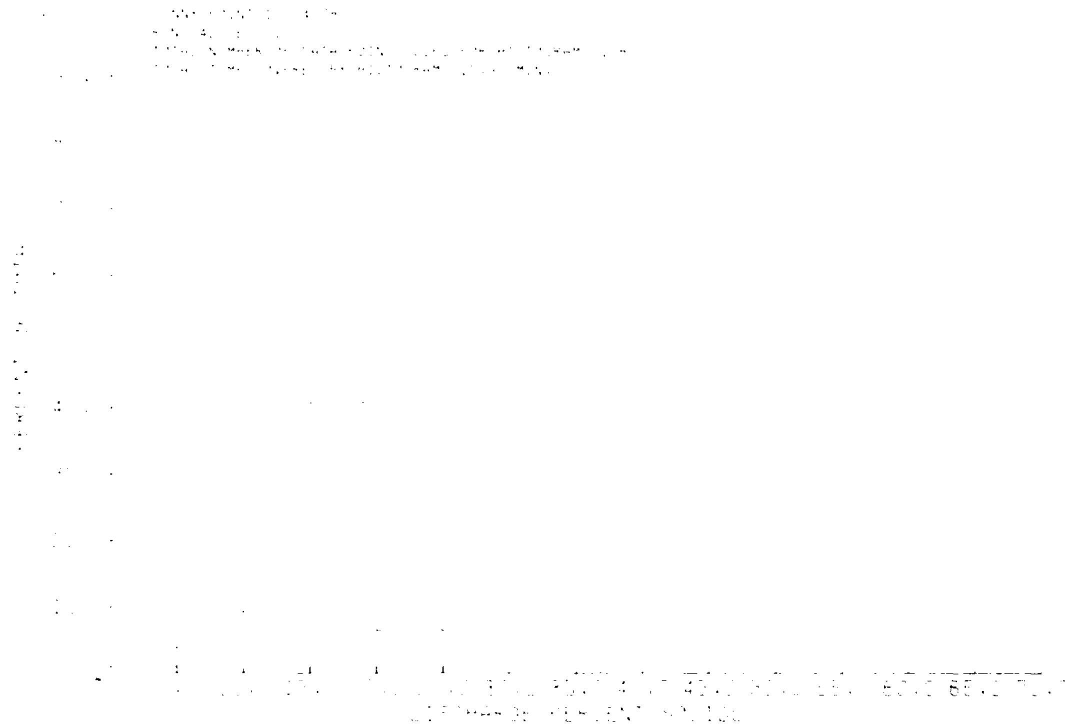
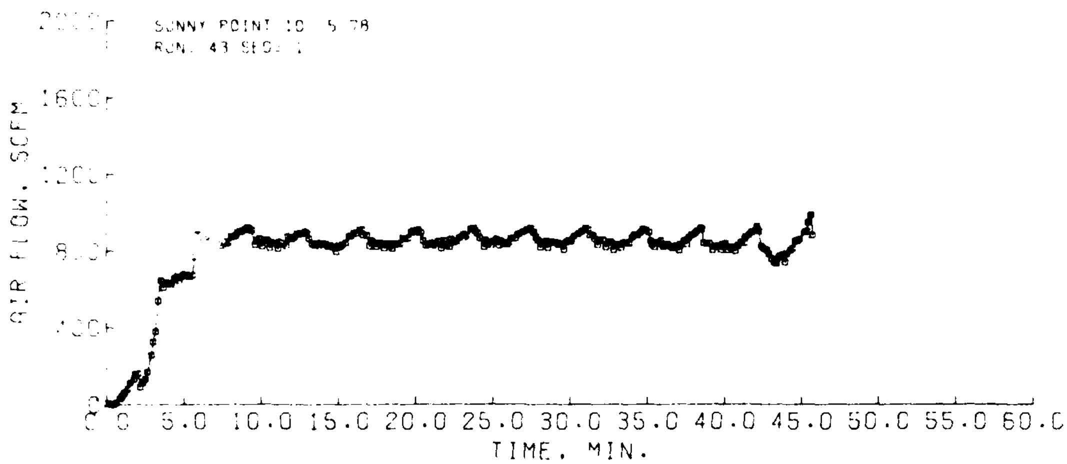
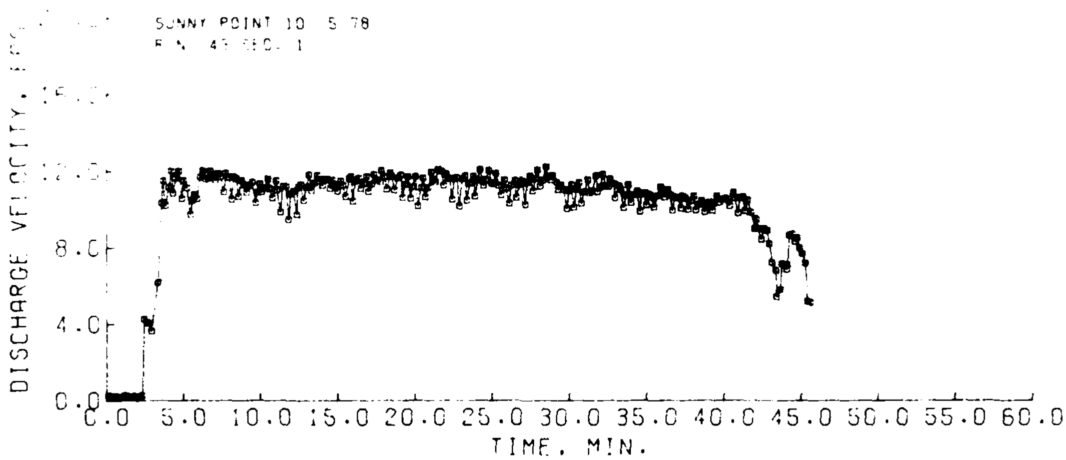


PLATE A86


SUNNY POINT 10 5 78
RUN: 43 SEQ: 1
1600
800
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 10 5 78
8.0
4.0
0.0
DISCHARGE VELOCITY
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

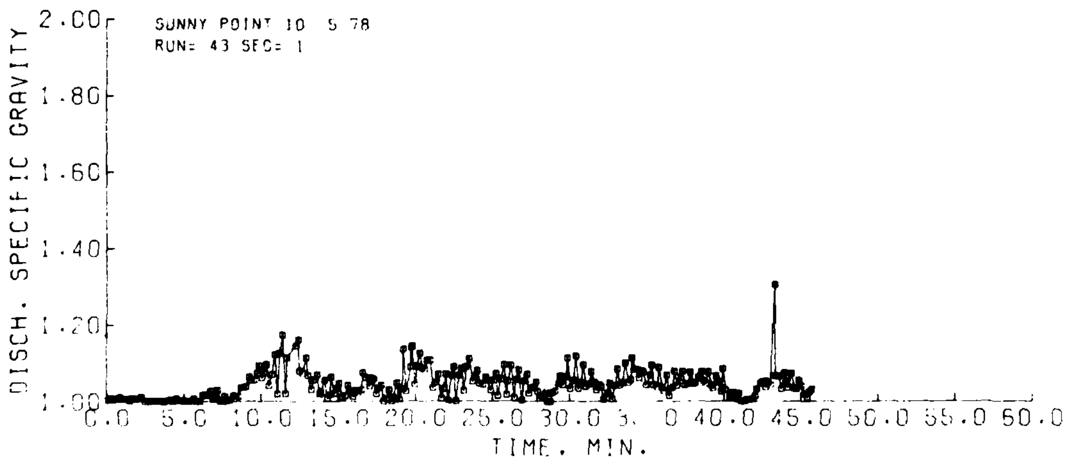

SUNNY POINT 10 5 78
RUN: 43 SEQ: 1
2.00
1.80
1.60
1.40
1.20
DISCH. SPECIFIC GRAVITY
0.0 5.0 10.0 15.0 20.0 25.0 30.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A87

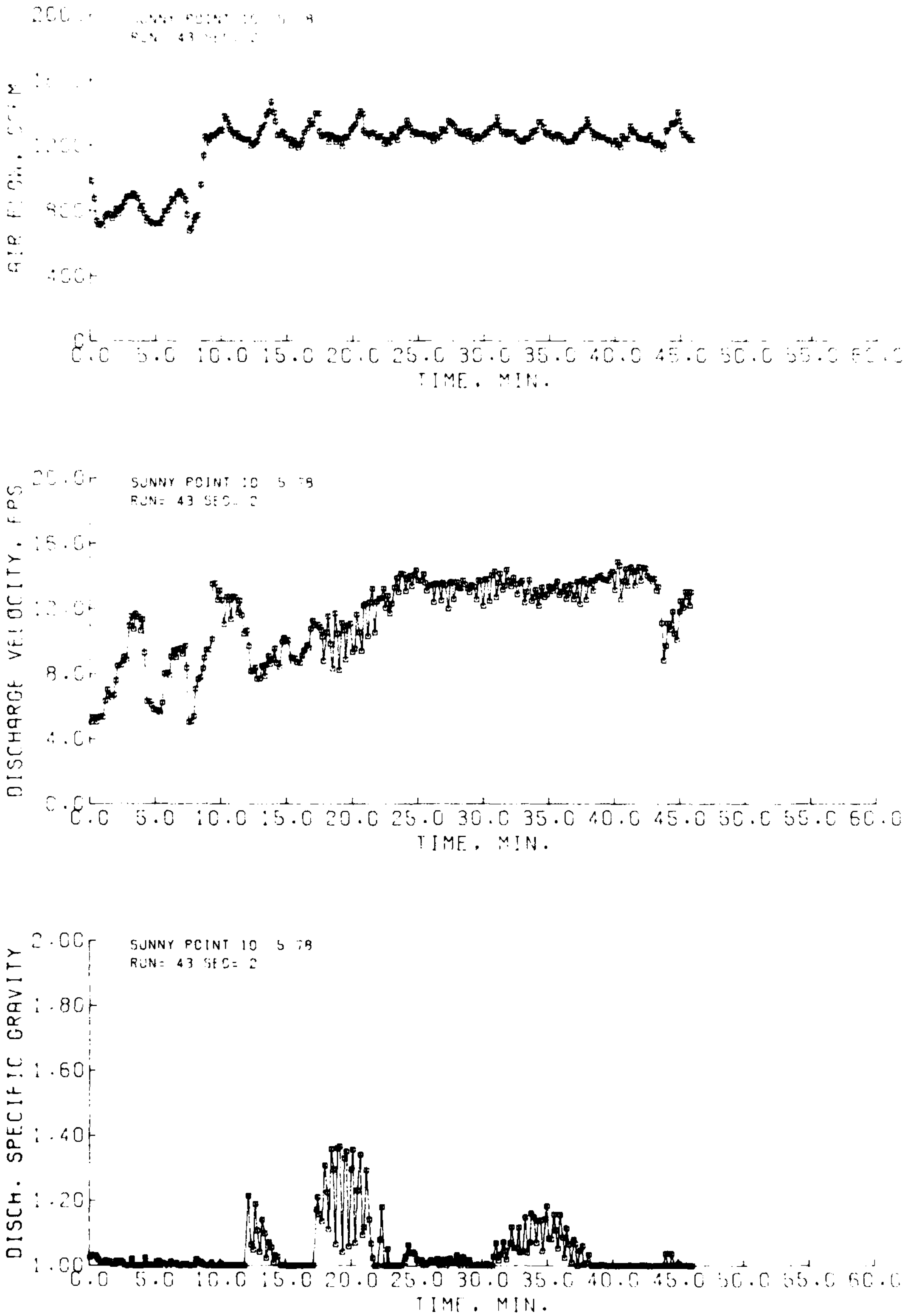
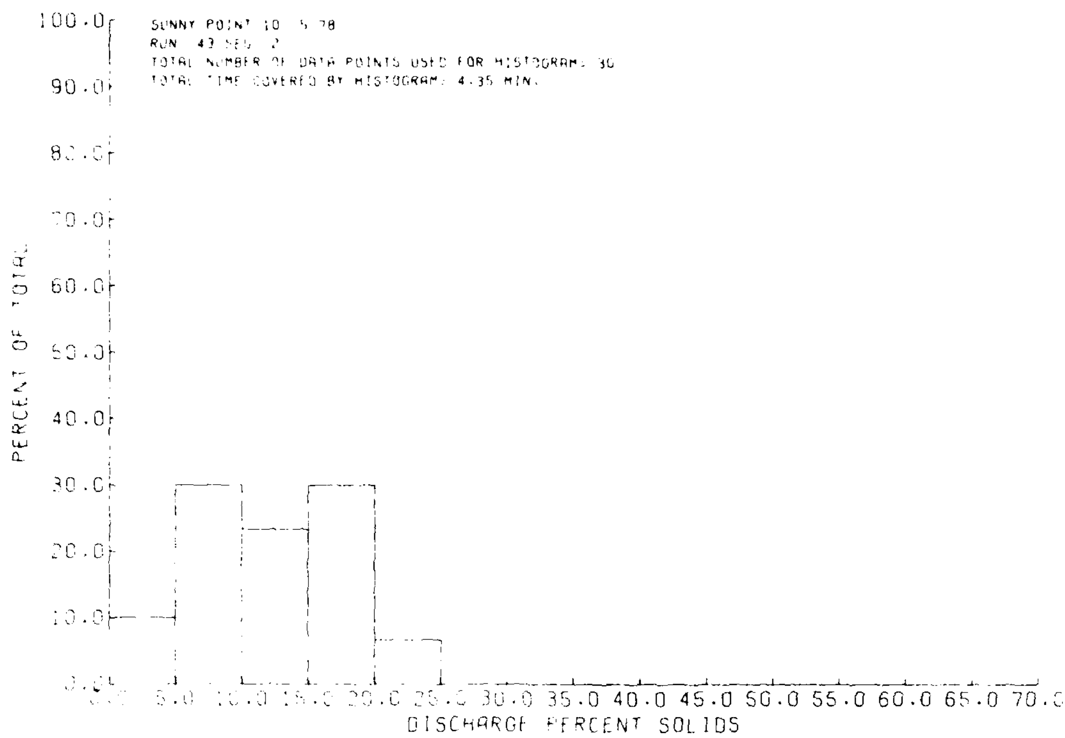

SUNNY POINT 10 5 78
RUN= 43 SEC= 2
AIR FLOW, CFM
TIME, MIN.
DISCHARGE VELOCITY, FPS
DISCH. SPECIFIC GRAVITY
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0

PLATE A88


SUNNY POINT 10 5 78
RUN 43 SEG 2
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM: 30
TOTAL TIME COVERED BY HISTOGRAM: 4.35 MIN.
PERCENT OF TOTAL
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
DISCHARGE PERCENT SOLIDS

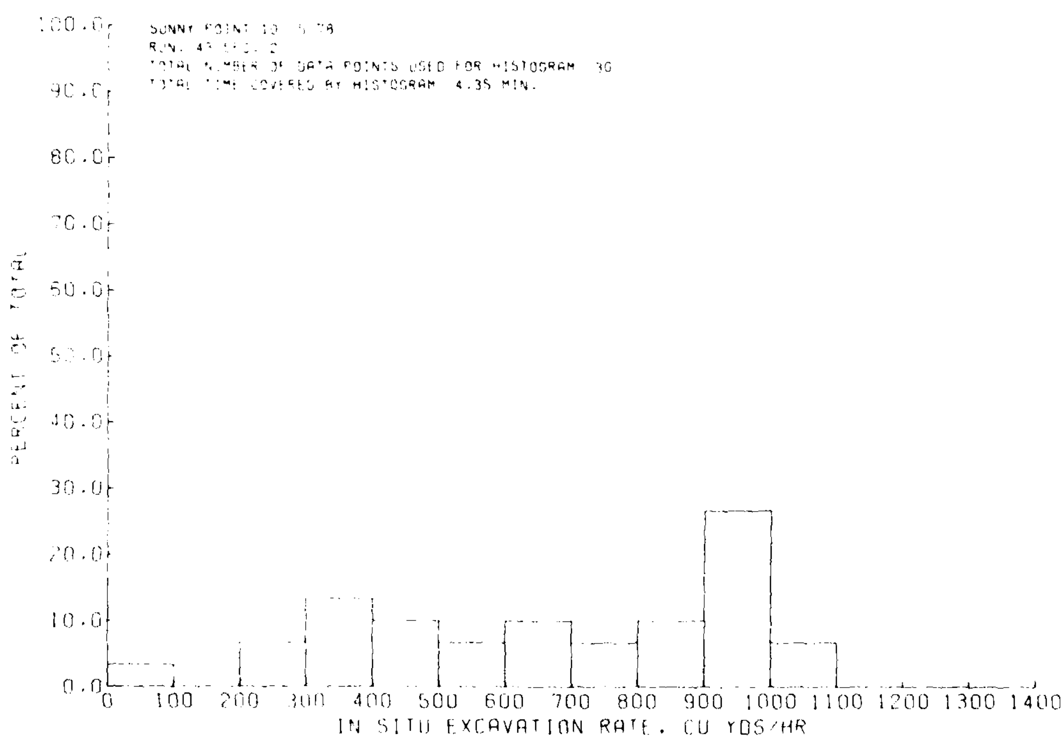
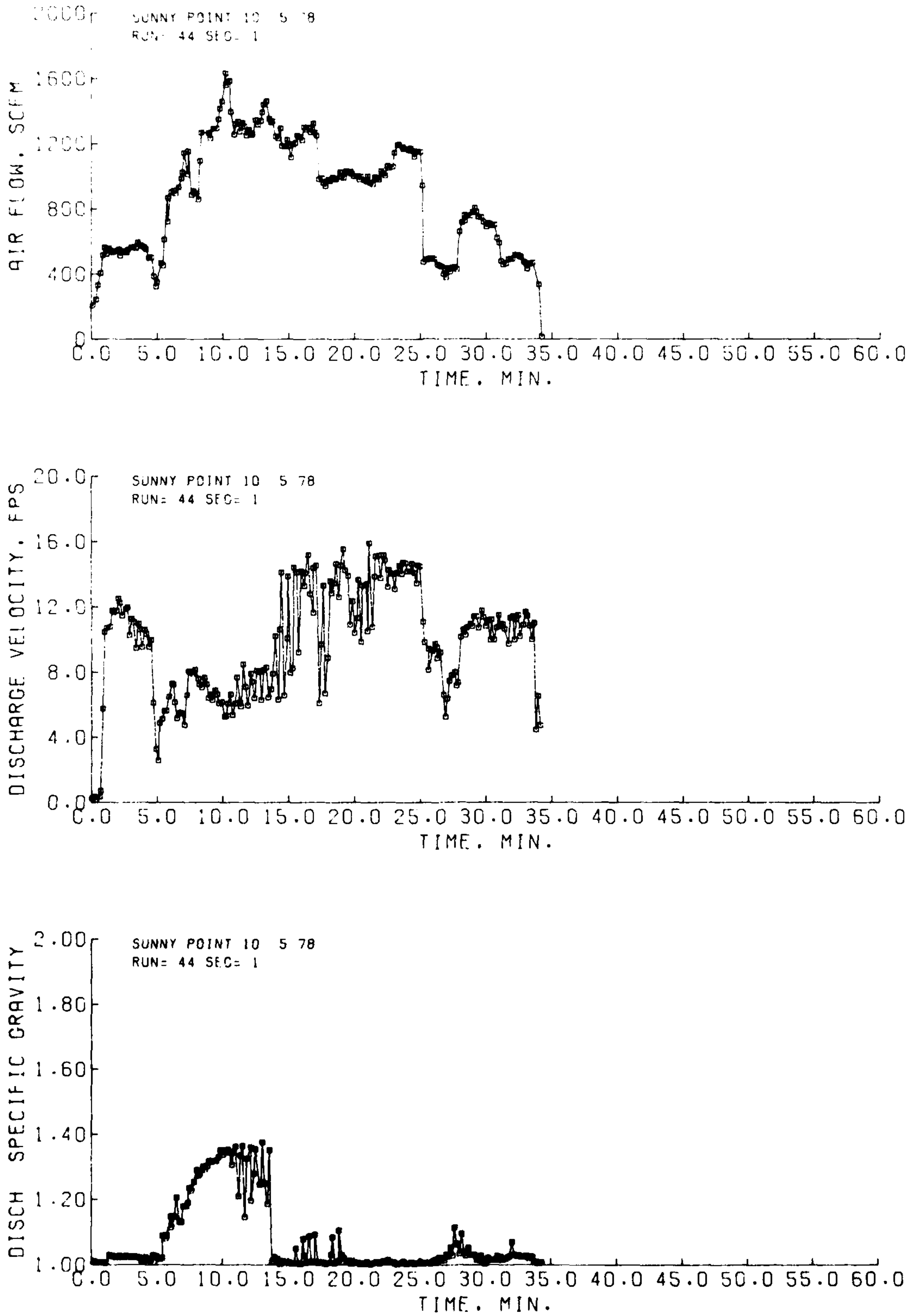
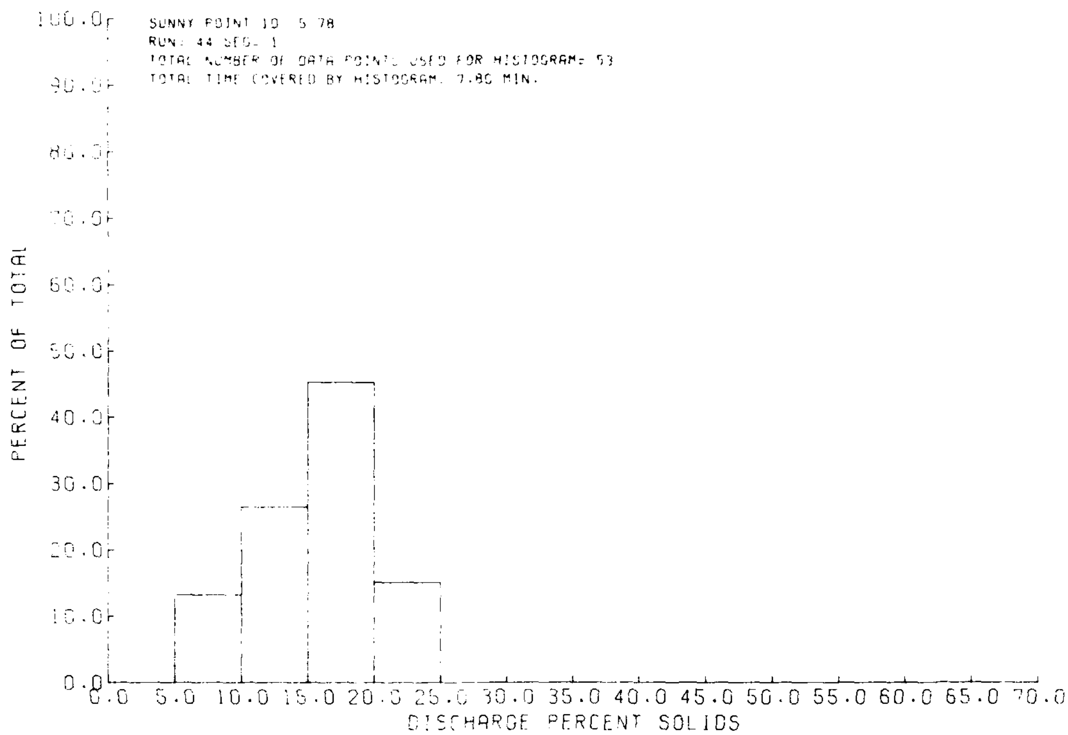

SUNNY POINT 10 5 78
RUN. 43 SEG. 2
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM 30
TOTAL TIME COVERED BY HISTOGRAM 4.35 MIN.
PERCENT OF TOTAL
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
IN SITU EXCAVATION RATE, CU YDS/HR

PLATE A89



SUNNY POINT 10 5 78
RUN= 44 SEC= 1
AIR FLOW, SCFM
TIME, MIN.
DISCHARGE VELOCITY, FPS
DISCH SPECIFIC GRAVITY

PLATE A90


SUNNY POINT 10 5 78
RUN: 44 SEG. 1
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM: 53
TOTAL TIME COVERED BY HISTOGRAM: 7.85 MIN.
PERCENT OF TOTAL
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0
DISCHARGE PERCENT SOLIDS

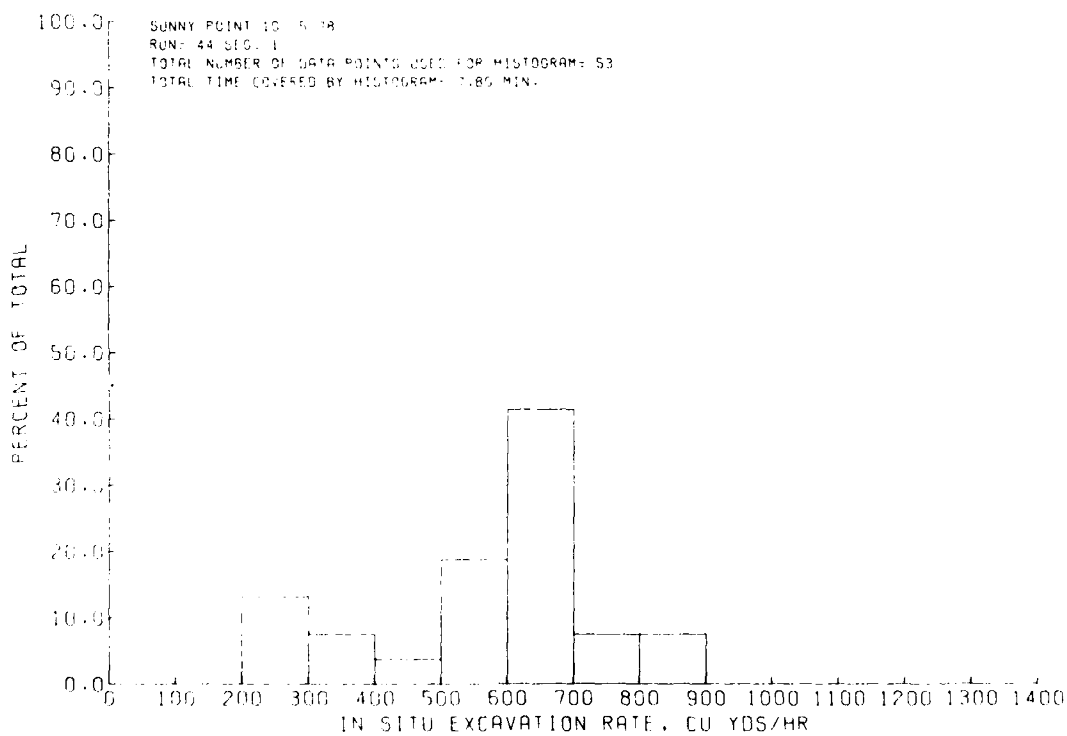
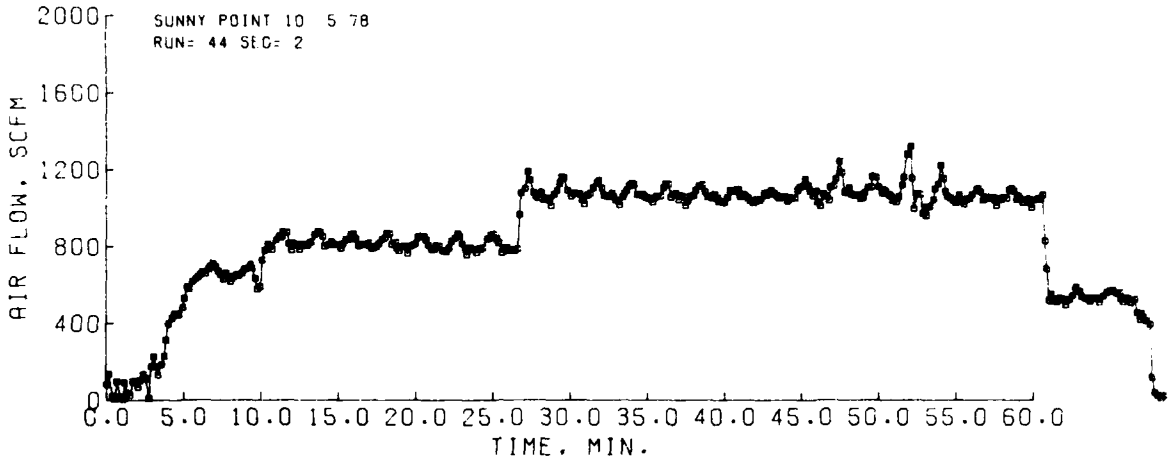
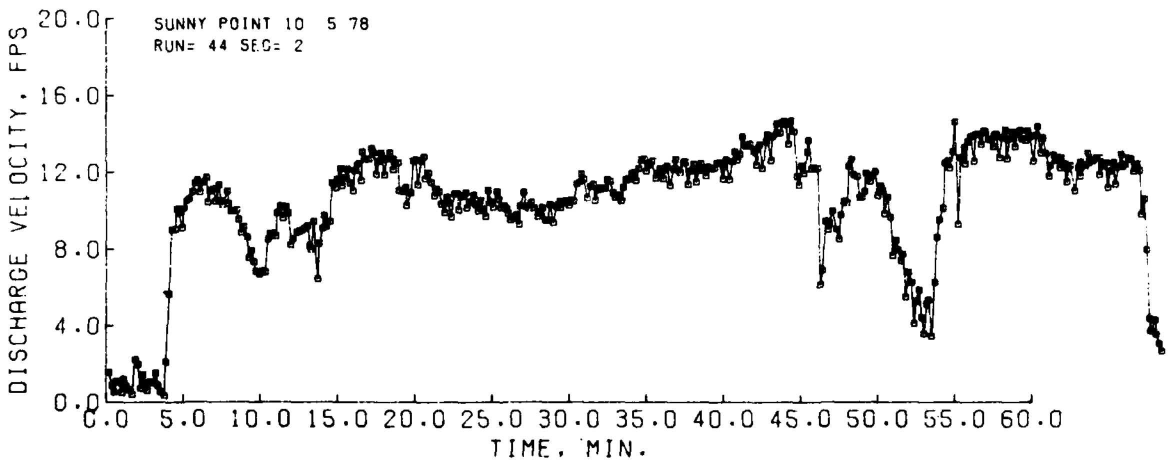

SUNNY POINT 10 5 78
RUN: 44 SEG. 1
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM: 53
TOTAL TIME COVERED BY HISTOGRAM: 7.85 MIN.
PERCENT OF TOTAL
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
IN SITU EXCAVATION RATE, CU YDS/HR

PLATE A91


SUNNY POINT 10 5 78
RUN= 44 SEC= 2
AIR FLOW, SCFM
2000
1600
1200
800
400
0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.


SUNNY POINT 10 5 78
RUN= 44 SEC= 2
DISCHARGE VELOCITY, FPS
20.0
16.0
12.0
8.0
4.0
0.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

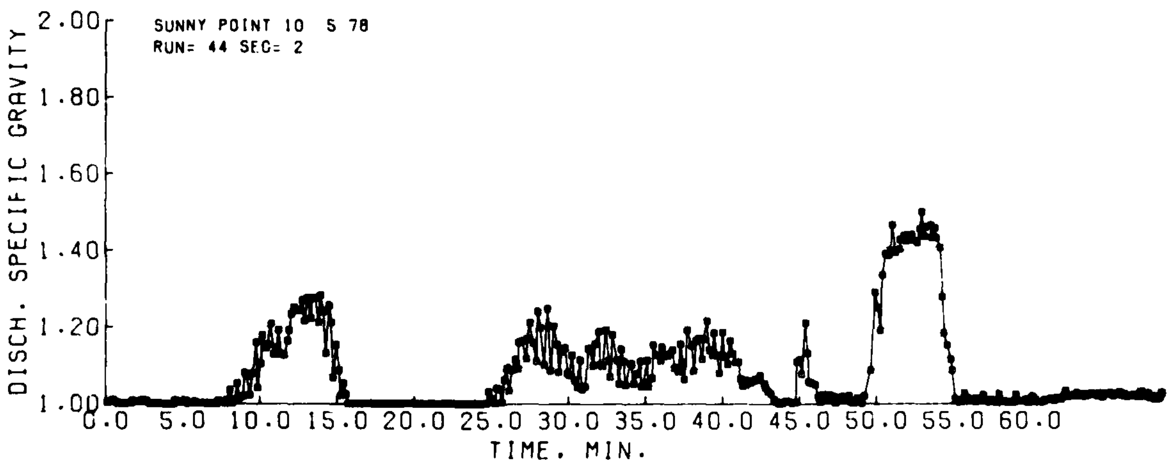
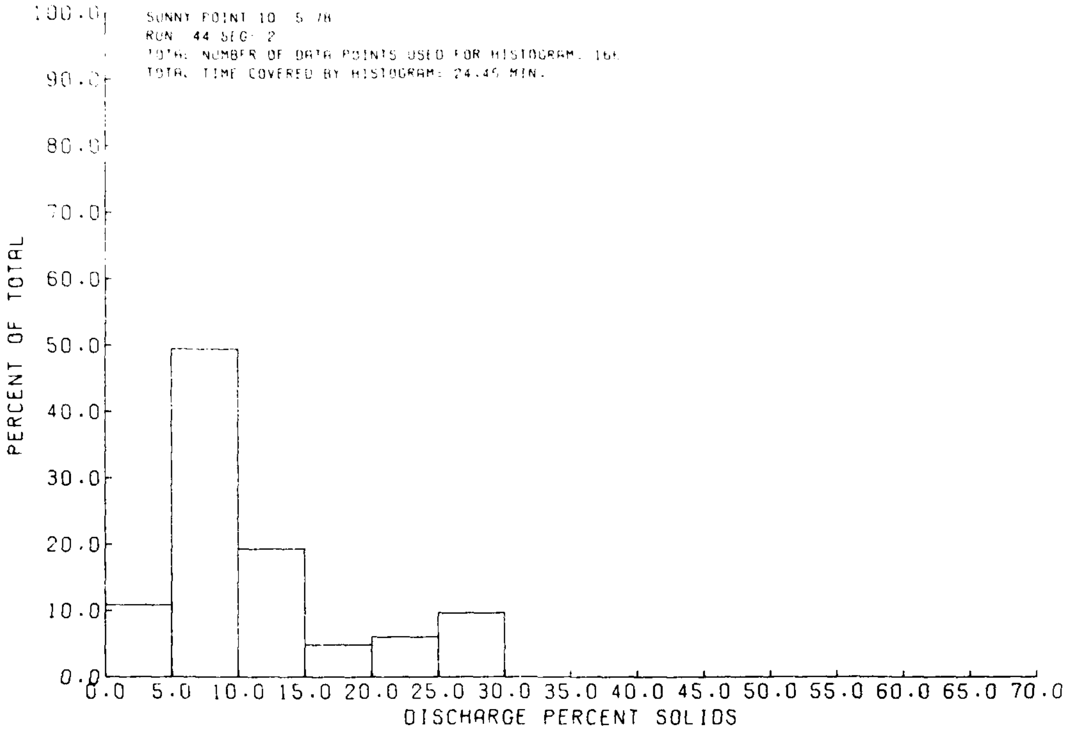

SUNNY POINT 10 5 78
RUN= 44 SEC= 2
DISCH. SPECIFIC GRAVITY
2.00
1.80
1.60
1.40
1.20
1.00
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0
TIME, MIN.

PLATE A92


SUNNY POINT 10 5 78
RUN 44 SEG 2
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM 166
TOTAL TIME COVERED BY HISTOGRAM: 24.45 MIN.
PERCENT OF TOTAL
DISCHARGE PERCENT SOLIDS

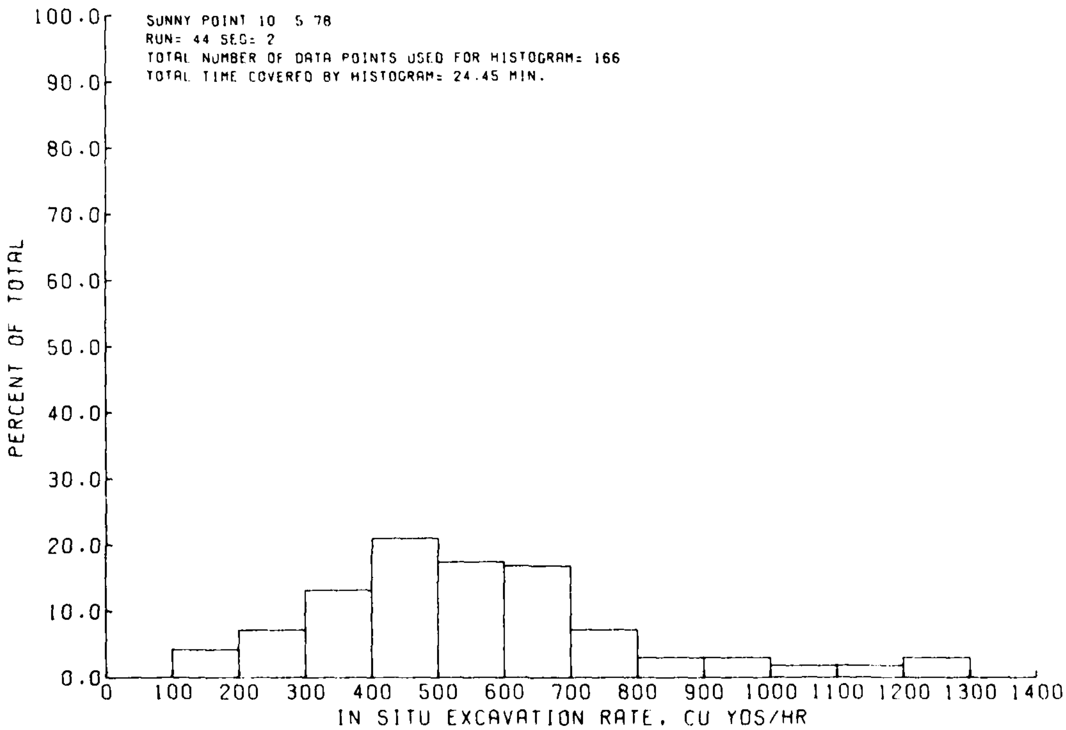

SUNNY POINT 10 5 78
RUN= 44 SEG= 2
TOTAL NUMBER OF DATA POINTS USED FOR HISTOGRAM= 166
TOTAL TIME COVERED BY HISTOGRAM= 24.45 MIN.
PERCENT OF TOTAL
IN SITU EXCAVATION RATE, CU YDS/HR

PLATE A93

APPENDIX B: ANALYSIS OF TURBIDITY TEST SAMPLES

1. Results of analyzing turbidity test samples are given in Tables B1-B6. Coding used to identify samples was as follows:

$$\underbrace{21}_{\substack{\text{run}\\ \text{no.}}} \; - \; \underbrace{\;\;A\;\;}_{\substack{\text{sample}\\ \text{adjacent}\\ \text{to pump}}} \quad \underbrace{10}_{\substack{\text{minutes}\\ \text{after}\\ \text{start}}} \; - \; \underbrace{\;\;5\;\;}_{\substack{\text{water}\\ \text{depth of}\\ \text{sample, ft}}}$$

2. Sample analysis results are given in Nephelometric Turbidity Units (NTU) and suspended solids in mg/ℓ. Equipment and methods used in analyzing samples are described in PART II of main text.

Table B1

Turbidity and Suspended Solids Analysis

Run 21 Adjacent to Pump

Sample	Turbidity NTU	Suspended Solids mg/ℓ	Comments
21-A0-0	8.0	4.37	Background sample; PNEUMA pump not operating
21-A0-5	7.0	3.85	
21-A0-10	5.0	3.90	
21-A0-15	8.0	4.82	
21-A10-0	8.0	4.20	
21-A10-5	5.0	4.70	
21-A10-10	6.0	5.10	
21-A10-15	13.0	6.55	
21-A20-0	11.5	5.25	
21-A20-5	6.0	5.05	
21-A20-10	6.0	4.15	
21-A20-15	16.0	6.50	
21-A30-0	7.0	3.10	
21-A30-5	8.0	5.05	
21-A30-10	17.5	5.45	
21-A30-15	10.0	5.25	
21-A40-0	14.0	4.90	
21-A40-5	8.5	5.25	
21-A40-10	30.0	9.25	
21-A40-15	14.0	5.55	
21-A50-0	4.0	4.42	
21-A50-5	5.0	4.00	
21-A50-10	7.0	4.35	
21-A50-15	15.5	16.30	
21-A60-0	5.0	3.70	
21-A60-5	5.0	5.00	
21-A60-10	5.0	3.95	
21-A60-15	28.0	8.50	

Table B2

Turbidity and Suspended Solids Analysis

Run 21 Downstream of Pump

Sample	Turbidity NTU	Suspended Solids mg/ℓ	Comments
21-10-0	5.0	11.50	25 ft downstream of pump
21-10-5	7.0	11.85	
21-10-10	7.0	4.15	
21-10-15	6.0	4.05	
21-20-0	7.0	4.55	25 ft downstream of pump
21-20-5	34.5	7.50	
21-20-10	12.0	5.85	
21-20-15	17.5	6.90	
21-30-0	8.0	4.47	25 ft downstream of pump
21-30-5	17.0	6.35	
21-30-10	20.5	5.95	
21-30-15	20.5	5.35	
21-40-0	8.0	5.12	100 ft downstream of pump
21-40-5	10.5	5.15	
21-40-10	17.0	7.45	
21-40-15	21.0	6.35	
21-50-0	13.0	8.80	100 ft downstream of pump in visible turbidity plume
21-50-5	68.0	13.40	
21-50-10	72.0	19.80	
21-50-15	40.0	21.50	
21-60-0	8.0	3.80	100 ft downstream of pump
21-60-5	5.0	4.40	
21-60-10	5.0	4.55	
21-60-15	60.0	26.40	

(Continued)

Table B2 (Concluded)

Sample	Turbidity NTU	Suspended Solids mg/ℓ	Comments
21-70-0	10.5	15.00	100 ft downstream of pump
21-70-5	57.0	38.40	
21-70-10	4.0	5.60	
21-70-15	14.0	7.40	
21-80-0	6.0	5.20	100 ft downstream of pump in visible turbidity plume
21-80-5	8.0	5.70	
21-80-10	10.0	6.40	
21-80-15	14.0	6.75	
21-90-0	5.0	5.30	100 ft downstream of pump
21-90-5	6.0	5.15	
21-90-10	8.0	5.45	
21-90-15	16.0	6.70	

Table B3

Turbidity and Suspended Solids Analysis

Run 22 Adjacent to Pump

Sample	Turbidity NTU	Suspended Solids mg/ℓ	Comments
22-A0-0	56.0	11.20	Background sample; PNEUMA pump not operating
22-A0-5	34.0	9.90	
22-A0-10	20.0	8.25	
22-A0-15	46.0	6.80	
22-A10-0	28.0	6.10	
22-A10-5	14.0	5.60	
22-A10-10	30.0	7.60	
22-A10-15	36.0	8.55	
22-A20-0	18.0	11.20	
22-A20-5	17.5	9.90	
22-A20-10	42.0	8.25	
22-A20-15	100.0	6.80	
22-A30-0	56.0	9.20	
22-A30-5	75.0	15.40	
22-A30-10	36.0	8.45	
22-A30-15	120.0	116.90	
22-A40-0	26.0	4.15	
22-A40-5	38.0	7.30	
22-A40-10	120.0	20.37	
22-A40-15	96.0	20.60	
22-A50-0	76.0	7.02	
22-A50-5	72.0	5.65	
22-A50-10	75.0	7.40	
22-A50-15	80.0	8.50	
22-A60-0	21.0	6.20	
22-A60-5	20.0	7.05	
22-A60-10	34.0	7.00	
22-A60-15	210.0	17.50	

Table B4

Turbidity and Suspended Solids Analysis

Run 22 Downstream of Pump

Sample	Turbidity NTU	Suspended Solids mg/ℓ	Comments
22-10-0	16.0	7.15	25 ft downstream of pump
22-10-5	28.0	7.40	
22-10-10	17.0	5.45	
22-10-15	8.0	7.20	
22-20-0	14.0	7.02	50 ft downstream of pump
22-20-5	18.5	5.65	
22-20-10	18.0	7.40	
22-20-15	20.0	8.50	
22-30-0	18.5	6.50	75 ft downstream of pump
22-30-5	19.0	10.80	
22-30-10	13.0	7.40	
22-30-15	40.0	8.95	
22-40-0	11.0	5.12	Background sample
22-40-5	16.0	5.15	
22-40-10	28.0	7.45	
22-40-15	19.0	6.35	
22-50-0	240.0	31.50	300 ft downstream of *Currituck* in turbidity plume from hopper overflow
22-50-5	18.5	5.35	
22-50-10	76.0	18.20	
22-50-15	16.0	5.40	
22-60-0	15.5	8.80	150 ft downstream of pump
22-60-5	95.0	13.40	
22-60-10	28.0	19.80	
22-60-15	16.0	21.50	

(Continued)

Table B4 (Concluded)

Sample	Turbidity NTU	Suspended Solids mg/ℓ	Comments
22-70-0	22.5	4.80	175 ft downstream of pump
22-70-5	42.0	2.05	
22-70-10	32.0	7.00	
22-70-15	72.0	18.50	
22-80-0	16.5	4.85	200 ft downstream of pump
22-80-5	15.0	4.30	
22-80-10	39.0	8.70	
22-80-15	56.0	11.70	
22-90-0	11.0	3.82	Background sample
22-90-5	14.0	4.65	
22-90-10	14.0	4.75	
22-90-15	50.0	9.30	

Table B5

Turbidity and Suspended Solids Analysis

Run 23 Adjacent to Pump

Sample	Turbidity NTU	Suspended Solids mg/ℓ	Comments
23-A0-0	13.0	5.55	Background sample; PNEUMA pump not operating
23-A0-5	6.0	4.25	
23-A0-10	5.0	4.55	
23-A0-15	13.5	5.95	
23-A10-0	9.0	4.22	
23-A10-5	8.5	5.00	
23-A10-10	10.0	5.00	
23-A10-15	14.0	6.10	
23-A20-0	11.0	7.00	
23-A20-5	11.5	2.90	
23-A20-10	26.0	7.45	
23-A20-15	54.0	24.80	
23-A30-0	8.0	6.55	
23-A30-5	8.0	7.00	
23-A30-10	9.0	5.70	
23-A30-15	26.0	10.65	
23-A40-0	8.0	4.52	
23-A40-5	8.0	4.65	
23-A40-10	16.5	5.75	
23-A40-15	76.0	18.60	
23-A50-0	8.0	4.00	
23-A50-5	8.0	4.75	
23-A50-10	19.0	5.60	
23-A50-15	70.0	6.80	

Table B6

Turbidity and Suspended Solids Analysis

Run 23 Downstream of Pump

Sample	Turbidity NTU	Suspended Solids mg/ℓ	Comments
23-10-0	8.0	4.42	25 ft downstream of pump
23-10-5	12.0	5.50	
23-10-10	56.0	24.60	
23-10-15	80.0	33.30	
23-20-0	8.0	2.60	Background sample
23-20-5	8.0	4.40	
23-20-10	9.0	4.65	
23-20-15	18.0	6.00	
23-30-0	7.0	3.95	75 ft downstream of pump
23-30-5	13.0	5.00	
23-30-10	10.0	4.95	
23-30-15	60.0	19.80	
23-40-0	126.0	13.40	Downstream of Currituck
23-40-5	54.0	16.60	
23-40-10	13.0	5.30	
23-40-15	40.0	11.10	
23-50-0	9.0	4.65	125 ft downstream of pump
23-50-5	8.0	5.15	
23-50-10	10.0	4.95	
23-50-15	10.5	4.90	
23-60-0	7.0	3.90	150 ft downstream of pump
23-60-5	8.0	5.30	
23-60-10	10.5	4.70	
23-60-15	14.0	7.60	

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Pumping performance and turbidity generation of
Model 600/100 PNEUMA Pump : Main Text and Appendixes
A and B / by Thomas W. Richardson ... [et al.]
(Hydraulics Laboratory, U.S. Army Engineer Waterways
Experiment Station). -- Vicksburg, Miss. : The Station ;
Springfield, Va. : available from NTIS, 1982.
82 p. in various pagings, 92 p. of plates ; ill. ;
27 cm. -- (Technical report ; HL-82-8)
Cover title.
"April 1982."
Final report.
Appendix C published separately.
"Prepared for Office, Chief of Engineers, U.S. Army."

1. Dredging. 2. Materials handling. 3. Pumping
machinery. 4. Sedimentation and deposition. 5. Turbidity.
I. Richardson, Thomas W. II. United States. Army.
Corps of Engineers. Office of the Chief of Engineers.
III. Series: Technical report (U.S. Army Engineer
Waterways Experiment Station) ; HL-82-8, Appendixes A and B.
TA7.W34 no.HL-82-8

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